The COHERENT Collaboration and coherent elastic neutrino-nucleus scattering as a new tool for nuclear and particle physics

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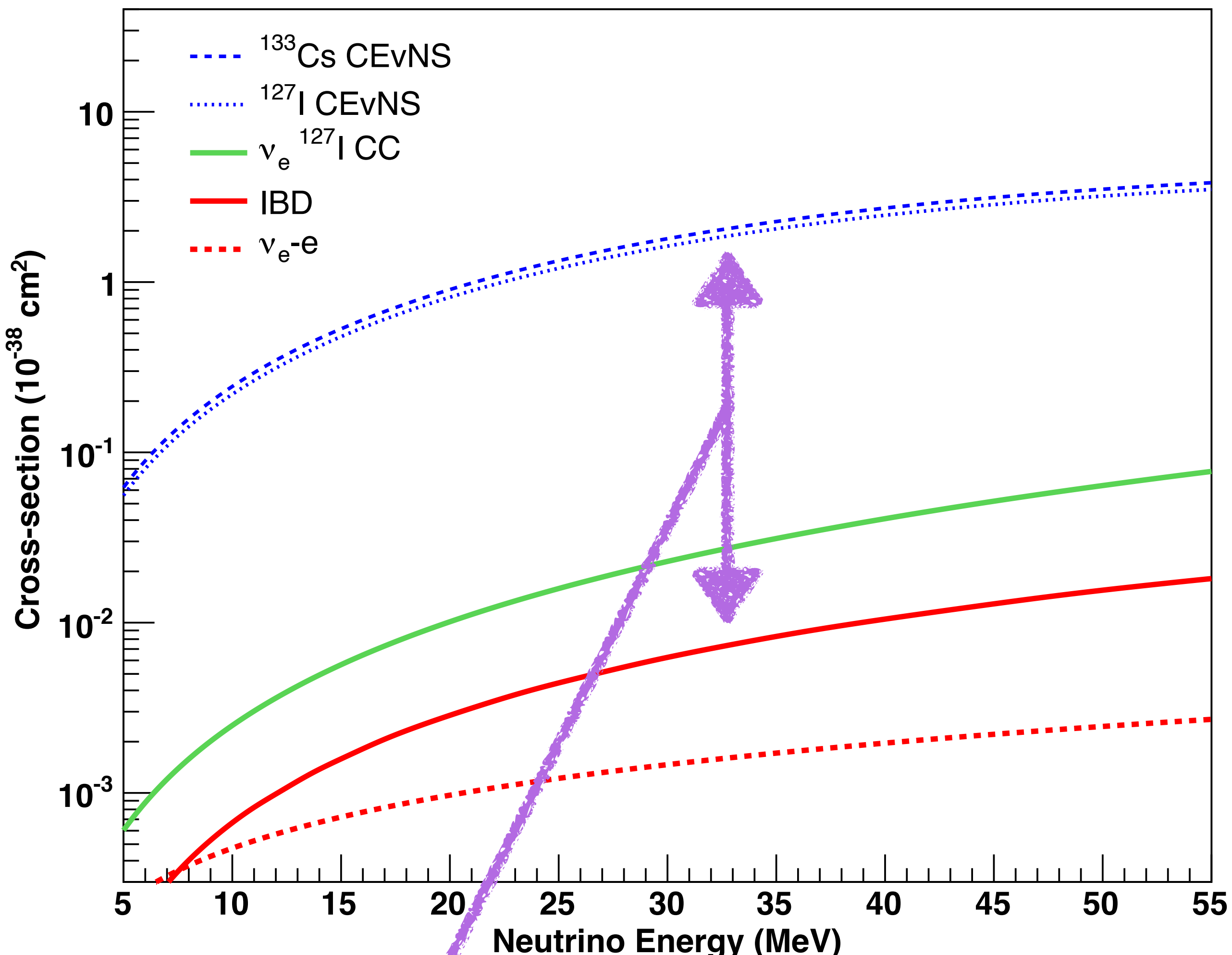
Coherent elastic neutrino-nucleus scattering (CEνNS)

- NC (flavor-independent) process postulated by D.Z. Freedman [1] / Kopeliovich & Frankfurt [2] in 1974

- In a CEνNS interaction, a neutrino scatters off of a nucleus whose nucleons recoil *in phase*, resulting in an enhanced cross section; total cross section scales approximately like N^2

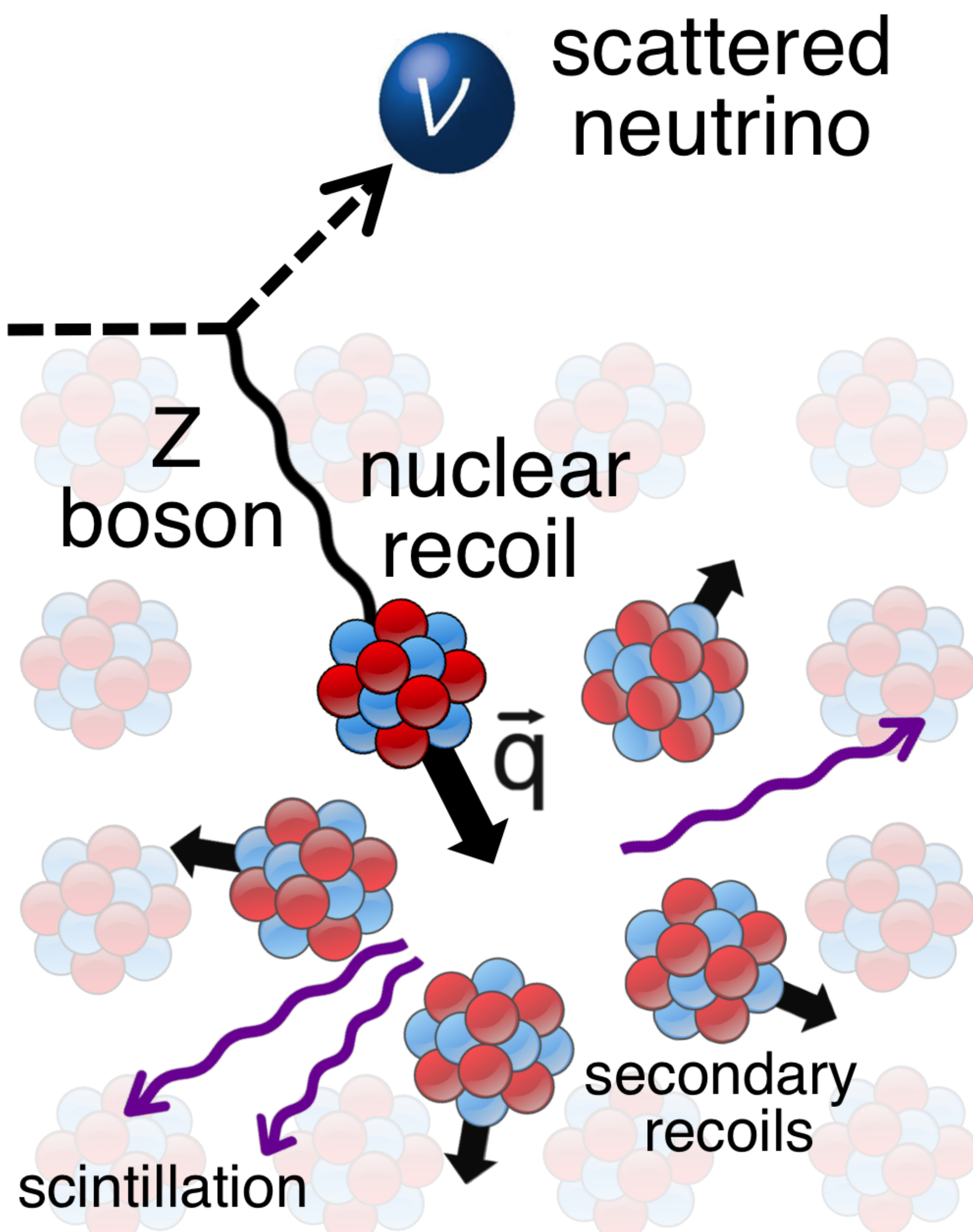
$$\sigma \approx \frac{G_F^2 N^2}{4\pi} E_\nu^2$$



Cross section can be orders of magnitude larger than IBD process used to first observe neutrinos!

[1] D.Z. Freedman, Phys. Rev. D 9 (1974)
[2] V.B. Kopeliovich and L.L. Frankfurt, ZhETF Pis. Red. 19 (1974)

“An act of hubris”

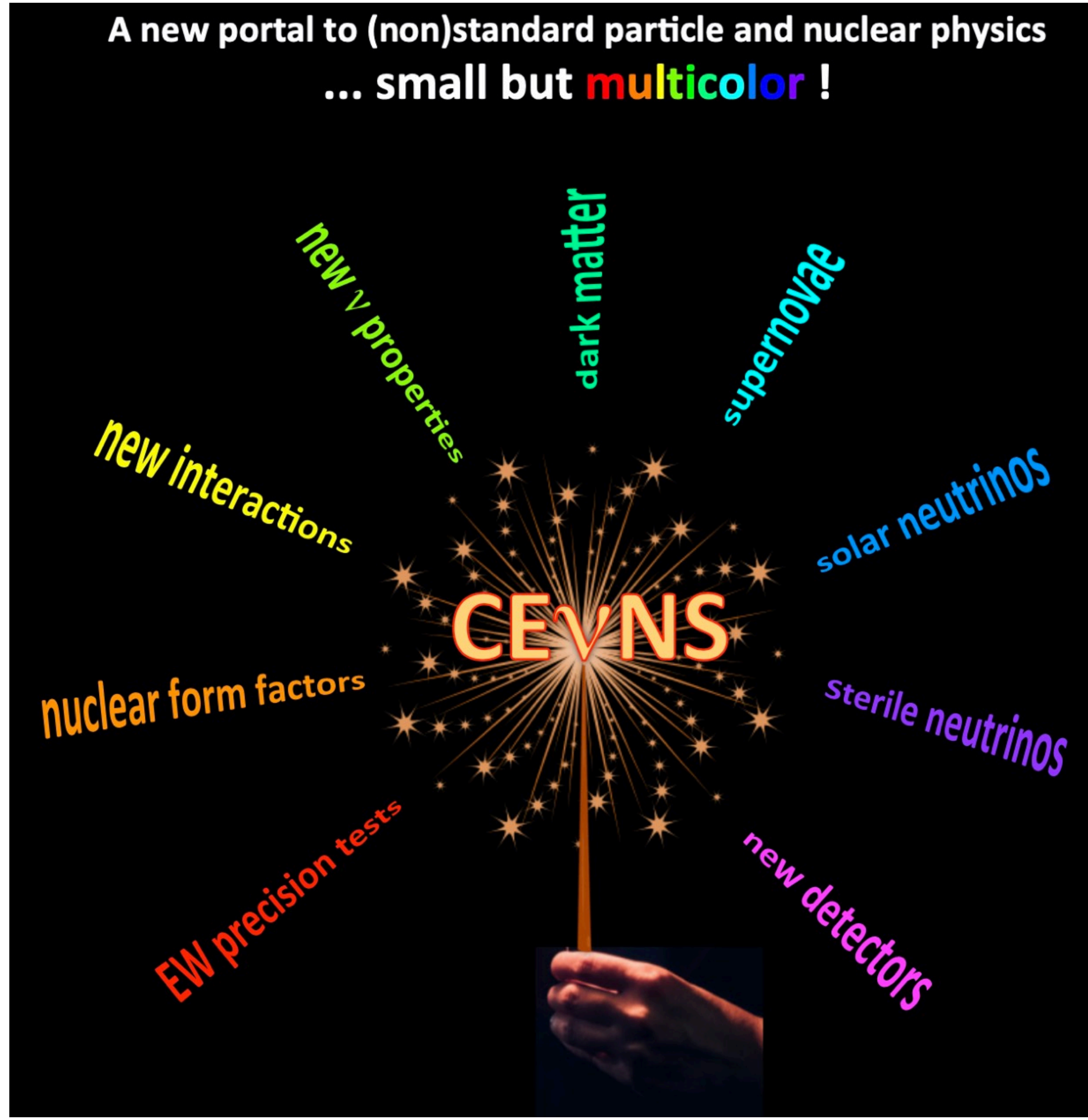


Freedman [1] noted that several factors combine to make CEνNS an exceptionally challenging process to observe

- Need an appropriate source of neutrinos
- Only evidence of the interaction is a low-energy recoiling nucleus
  - Heavier nuclei: higher cross section but lower recoil energies
  - Nuclear recoil signal yields are quenched, i.e. reduced compared to signal from electrons of same energy by a factor called the quenching factor (QF)
  - Detector performance hard to calibrate
- Very-low-threshold detectors are very sensitive to backgrounds
  - Neutron backgrounds are particularly dangerous: produce low-energy nuclear recoils just like CEνNS

[1] D.Z. Freedman, Phys. Rev. D 9 (1974)

First CEνNS observation — COHERENT 2017



- COHERENT Collaboration performed first observation of CEνNS in 2017
- The many physics sensitivities of the process have been illustrated in the results derived from this data

Image from E. Lisi, Neutrino 2018, 10.5281/zenodo.1286745

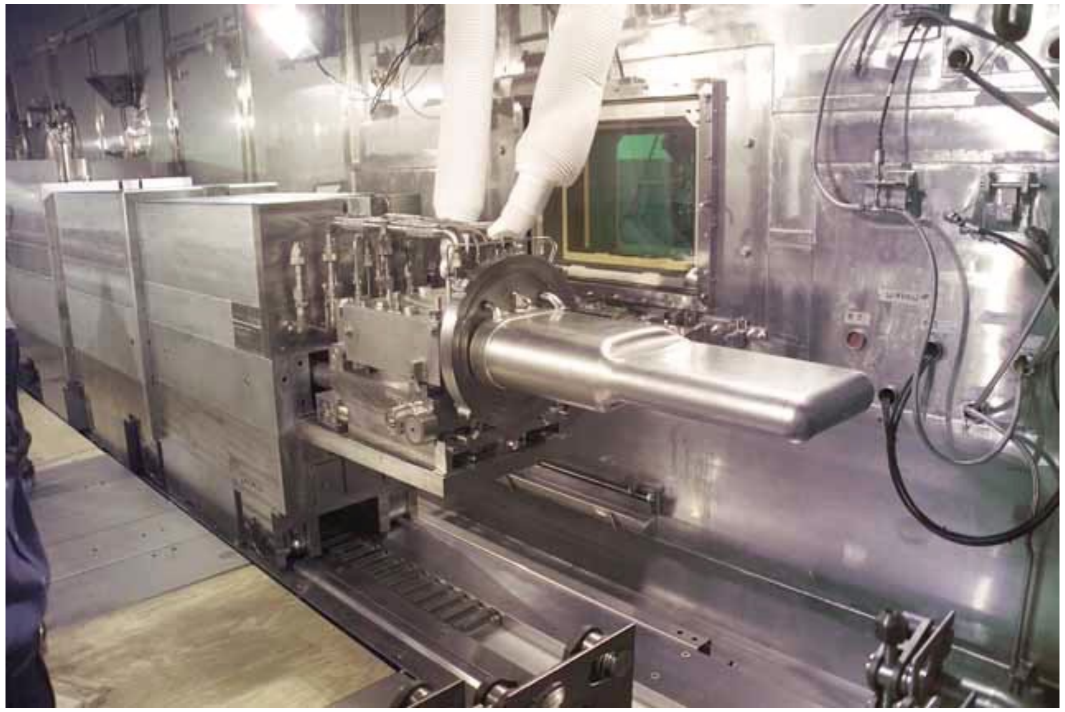
The COHERENT Collaboration

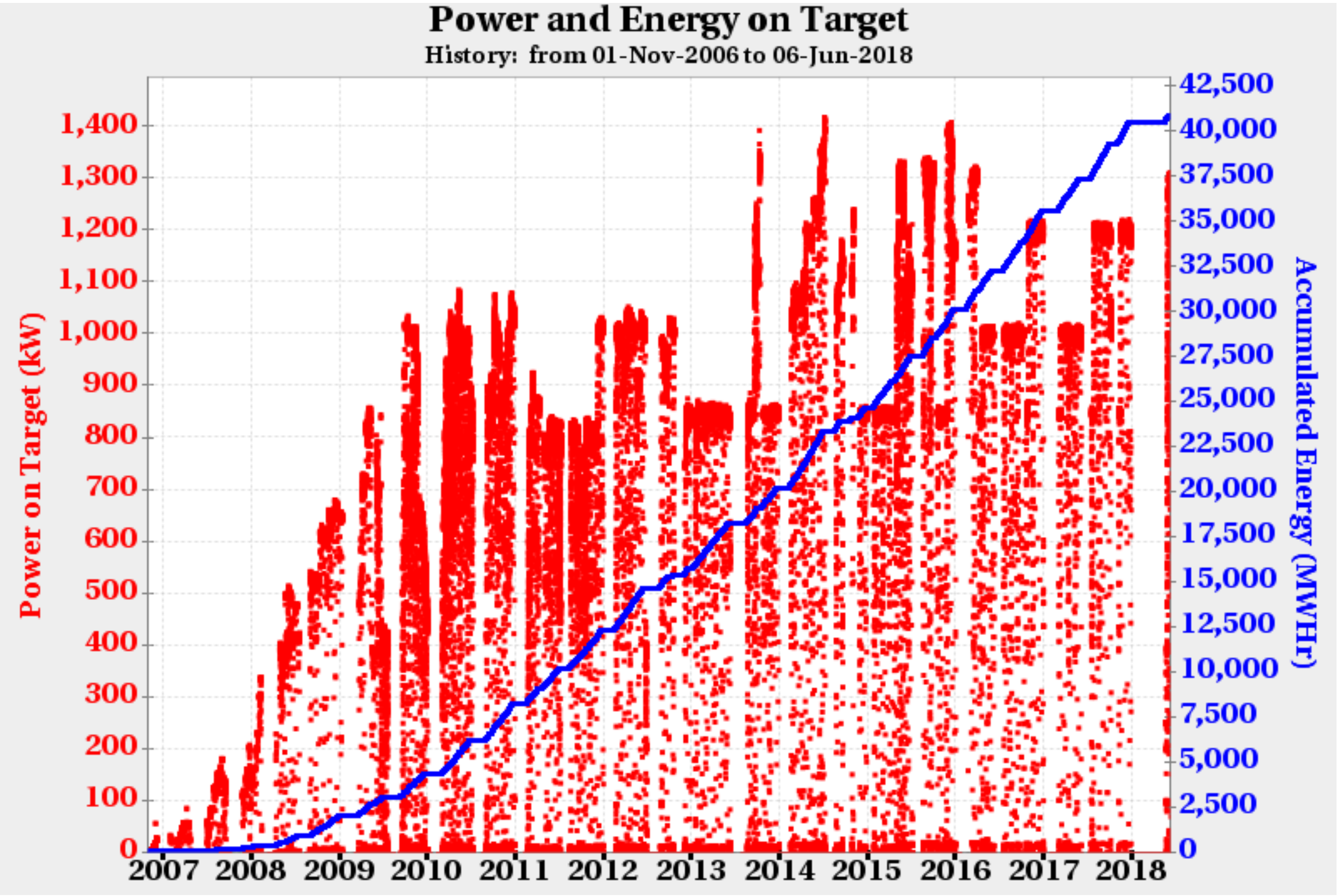
- Goal: **unambiguous observation** of CEνNS using multiple nuclear targets / detector technologies
  - Leverage detector advances from dark-matter community
  - Utilize intense, pulsed neutrino source provided by Spallation Neutron Source (SNS)
  - Use of different nuclear targets allows for measurement of characteristic N^2 cross-section dependence and some added analysis advantages
- Pioneering CEνNS detector: CsI[Na]

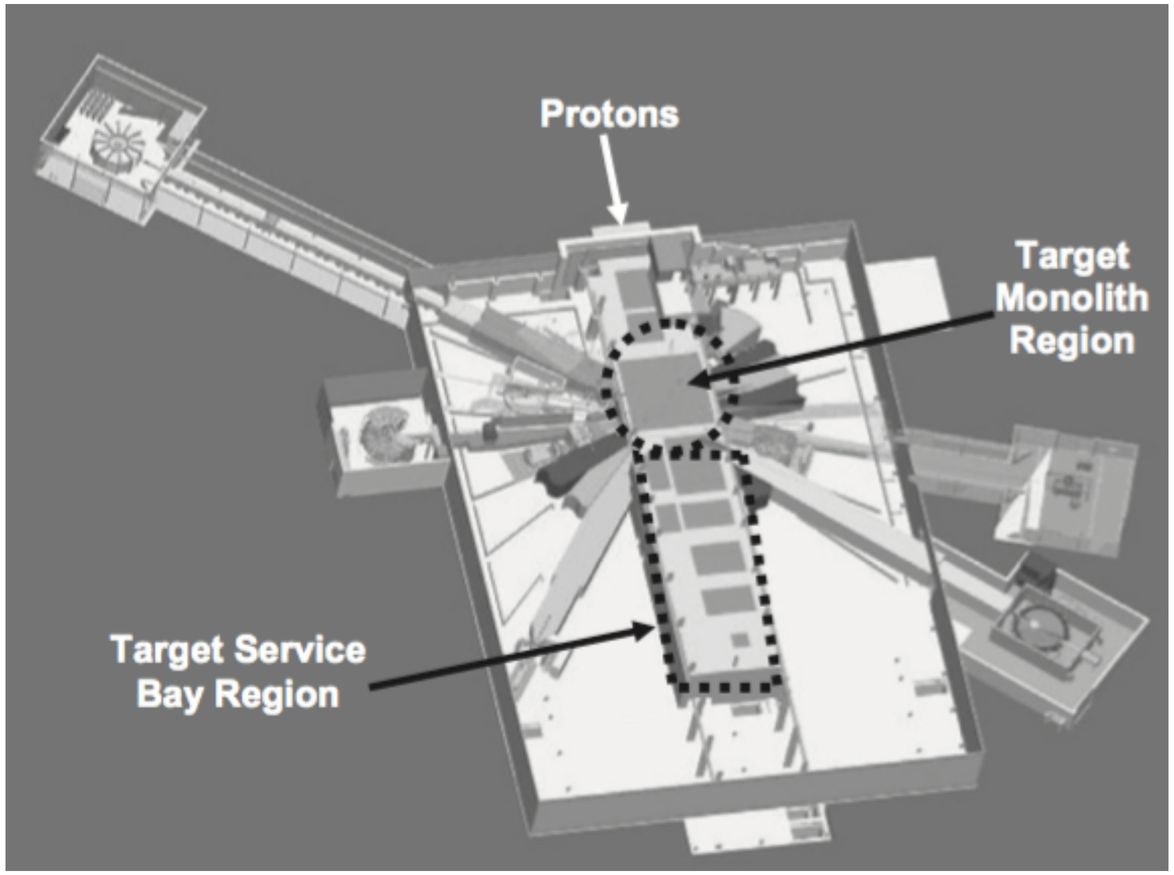
The Spallation Neutron Source

- Located at Oak Ridge National Lab, near Knoxville, TN, USA
- The SNS bombards a liquid mercury target with a ~1-GeV proton beam pulsed at 60 Hz; each beam pulse is ~700-ns wide
- Neutrinos are produced by decay of ***stopped*** *pions and muons*, resulting in flux with well-defined spectral and timing characteristics

The Spallation Neutron Source



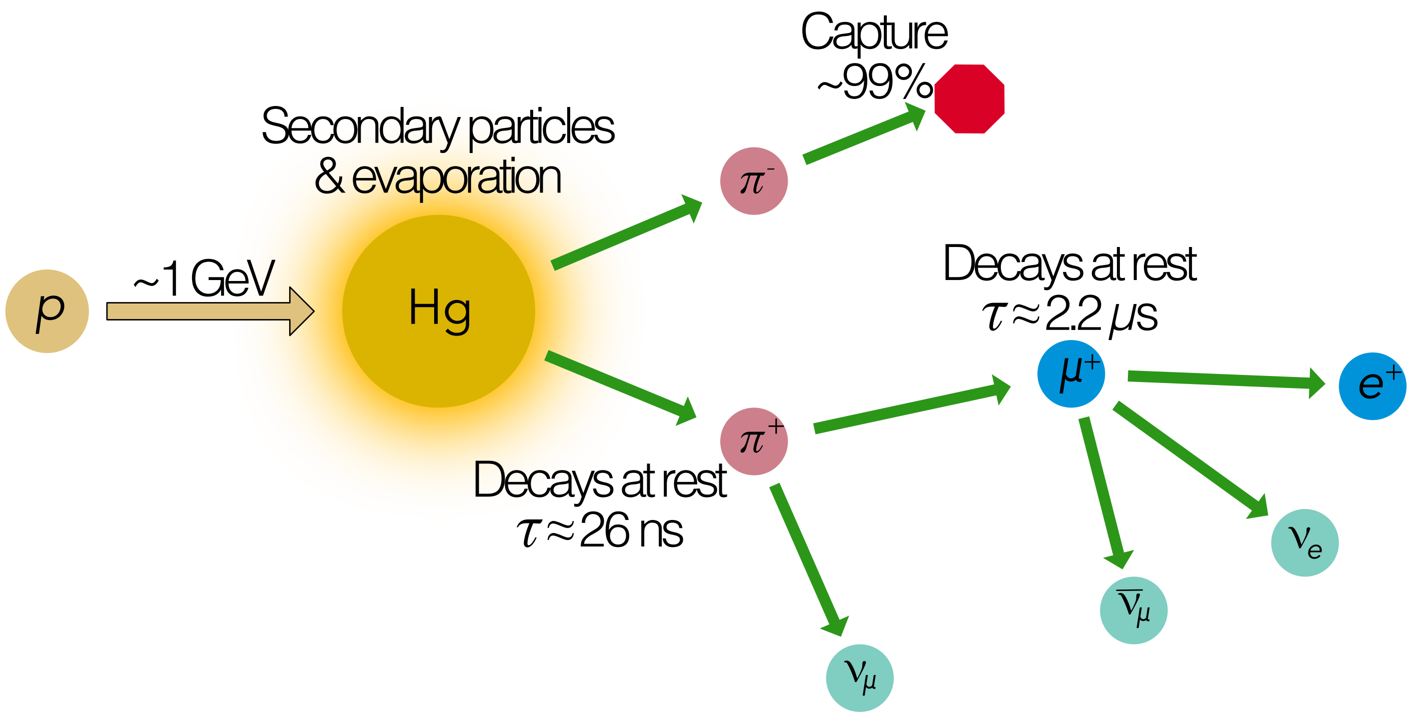


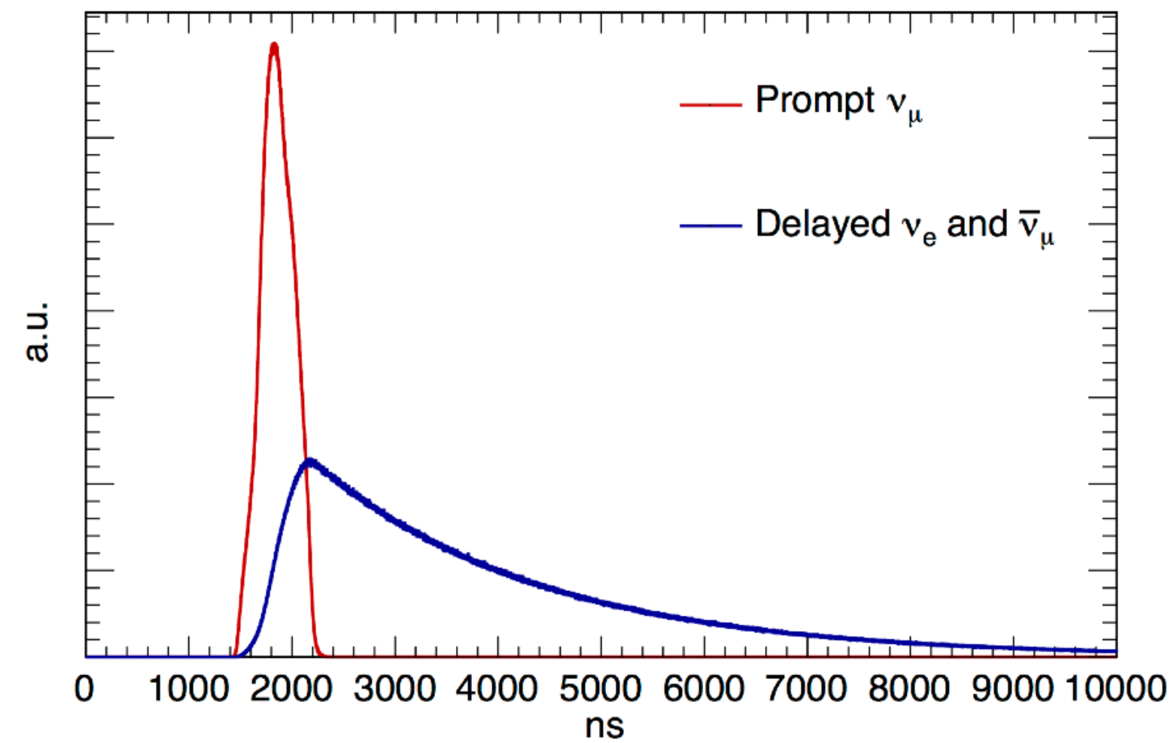


Most intense pulsed neutron source in the world

Images from: (top) https://neutrons.ornl.gov,
(bottom) J.R. Haines *et al.*, Nucl Instrum Meth A 764 (2014)
Figure from https://status.sns.ornl.gov/beam.jsp

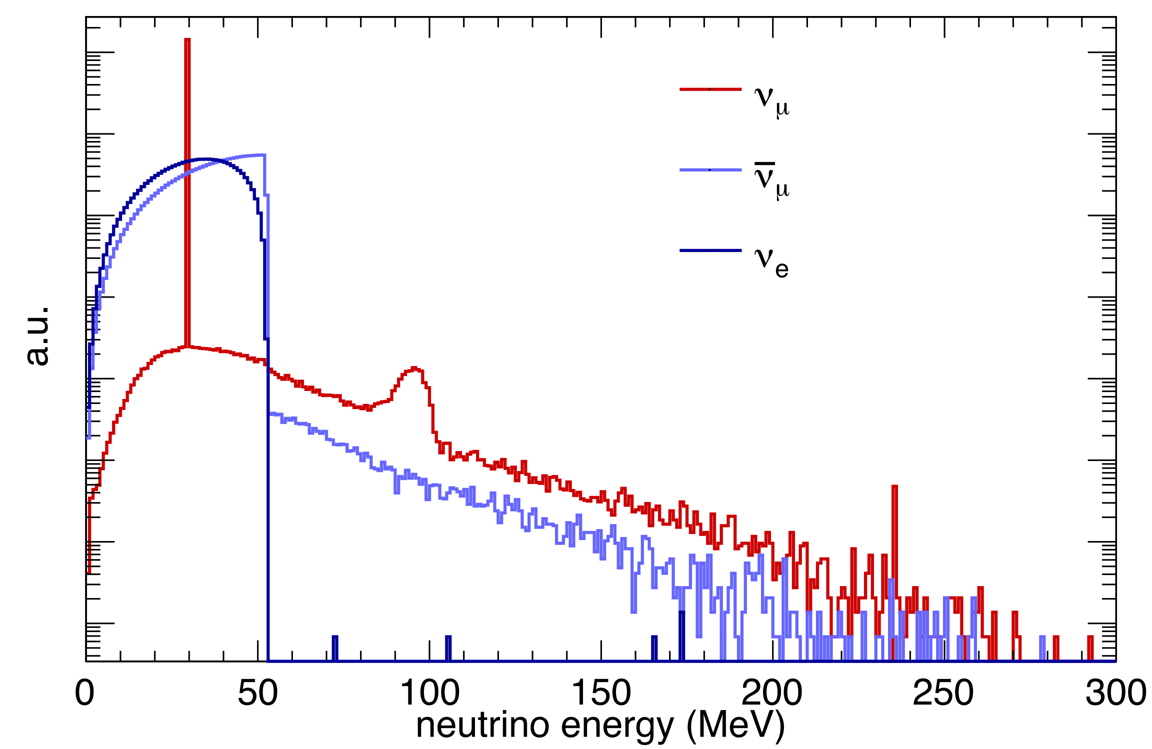
The Spallation ~~Neutron~~ Neutrino Source





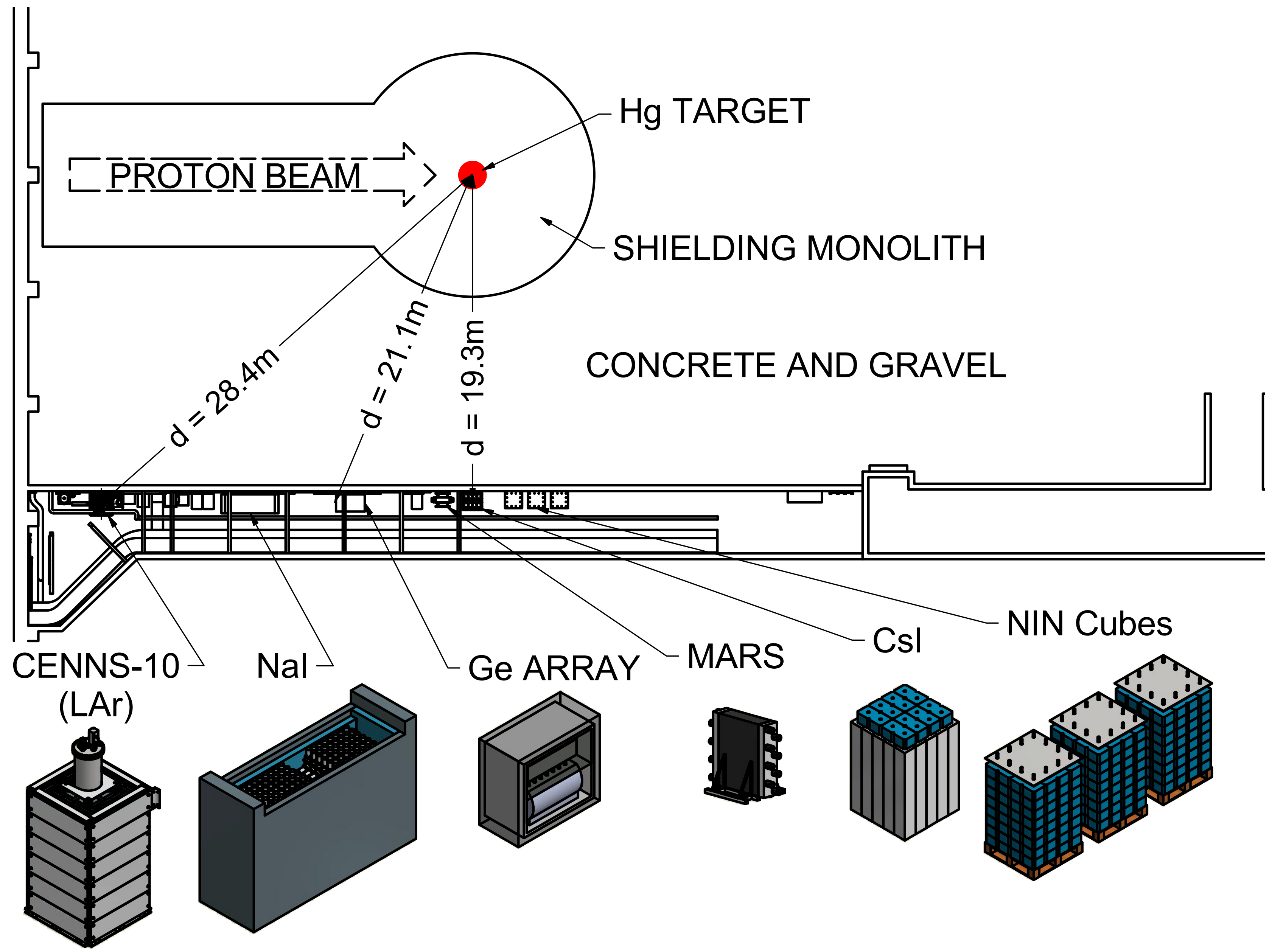
- High-fidelity GEANT4 simulation starts with proton beam; energy spectra very near analytical approximations

- Massive reduction in steady-state backgrounds through timing ($\mathcal{O}(1000)$); facility-wide timing signal can be used to trigger DAQ, both during beam-on and -off periods



Siting and backgrounds

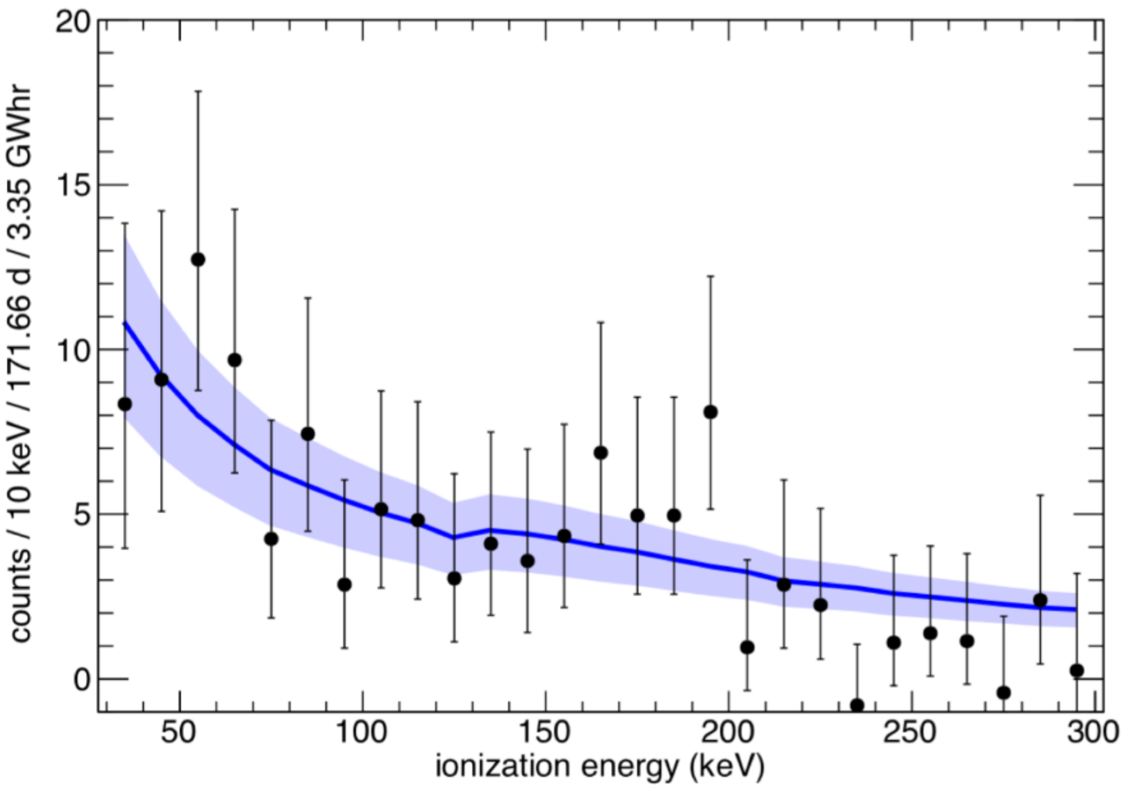
- Backgrounds depend significantly on siting at SNS
  - Extensive background measurement campaign
- COHERENT experiments located in ~~a basement hallway~~ *neutrino alley*
  - ~8 m.w.e. overburden
  - 20- to 30-m from target
- Primary backgrounds in neutrino alley:
  - Prompt SNS neutrons
  - Neutrino-induced neutrons (NINs)

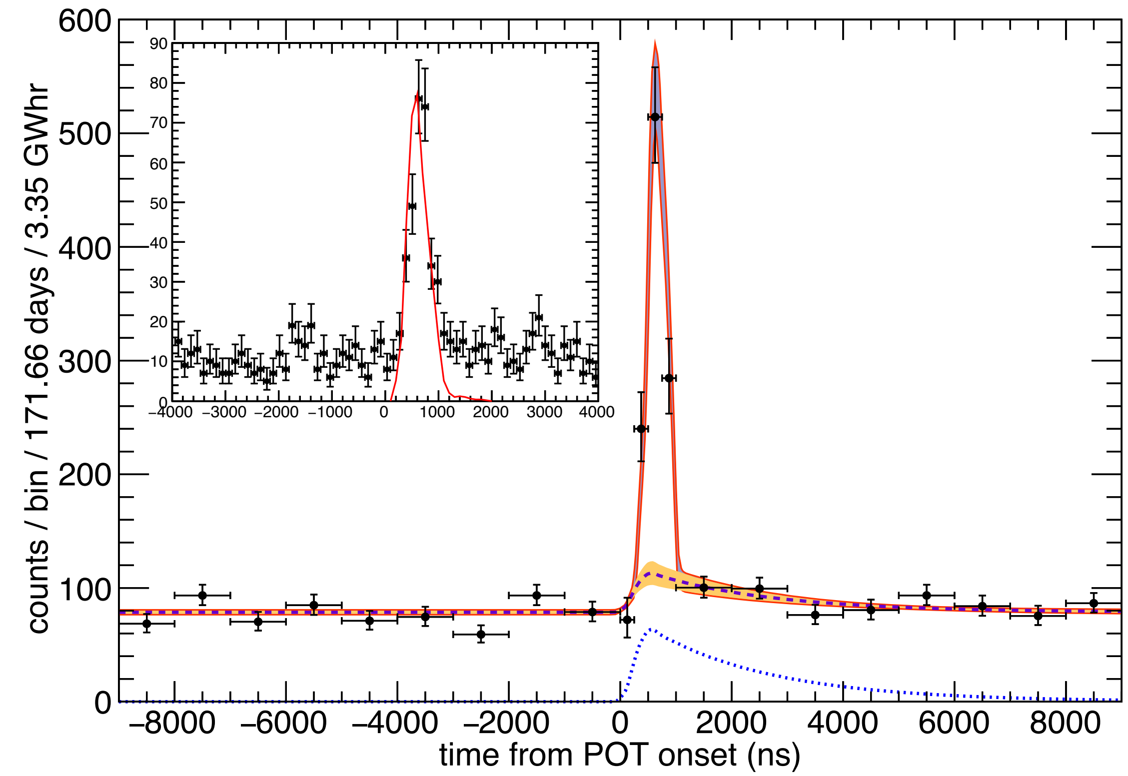


Approx ν flux at CsI[Na] location

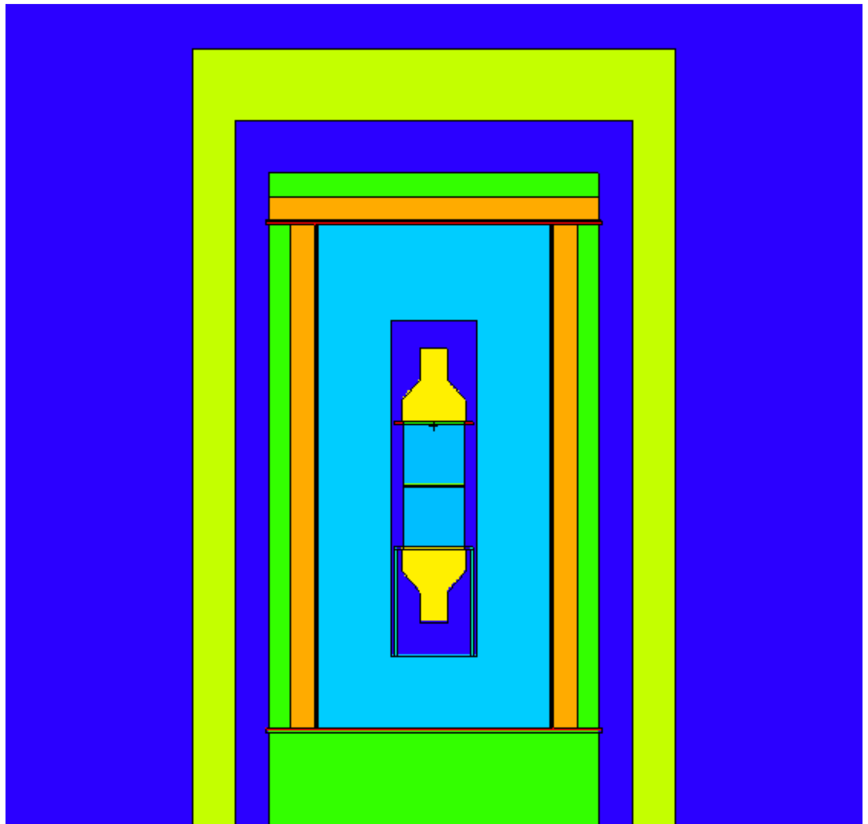
1e7 ν / cm^2 / s / flavor

In situ measurement of neutron backgrounds



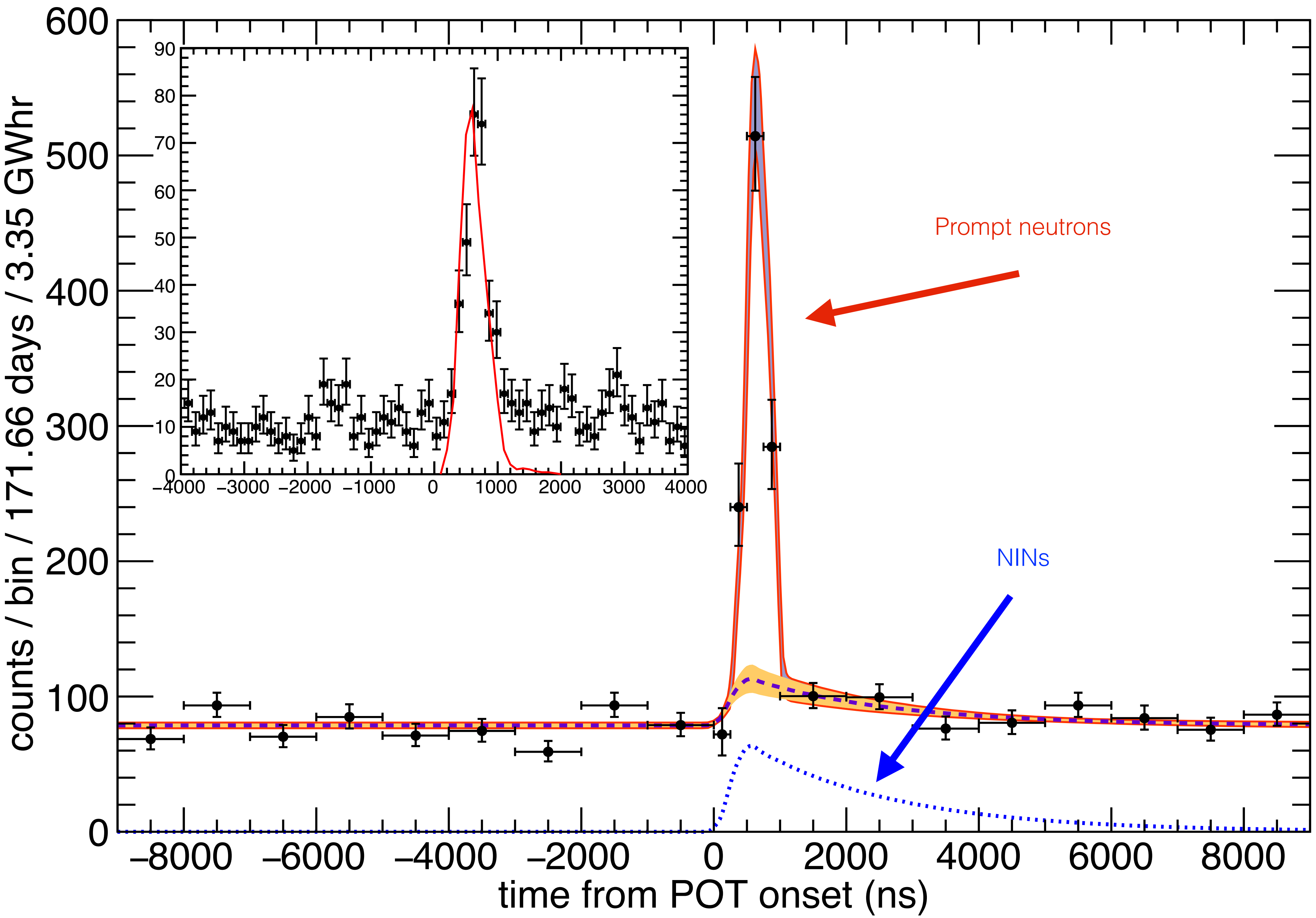


- Prior to CEνNS search, neutron detection system installed at location of CsI[Na] detector
- Data informed model of prompt SNS neutron energy distribution
- Established understanding of beam timing w.r.t. SNS timing signal



COHERENT SNS

In situ measurement of neutron backgrounds

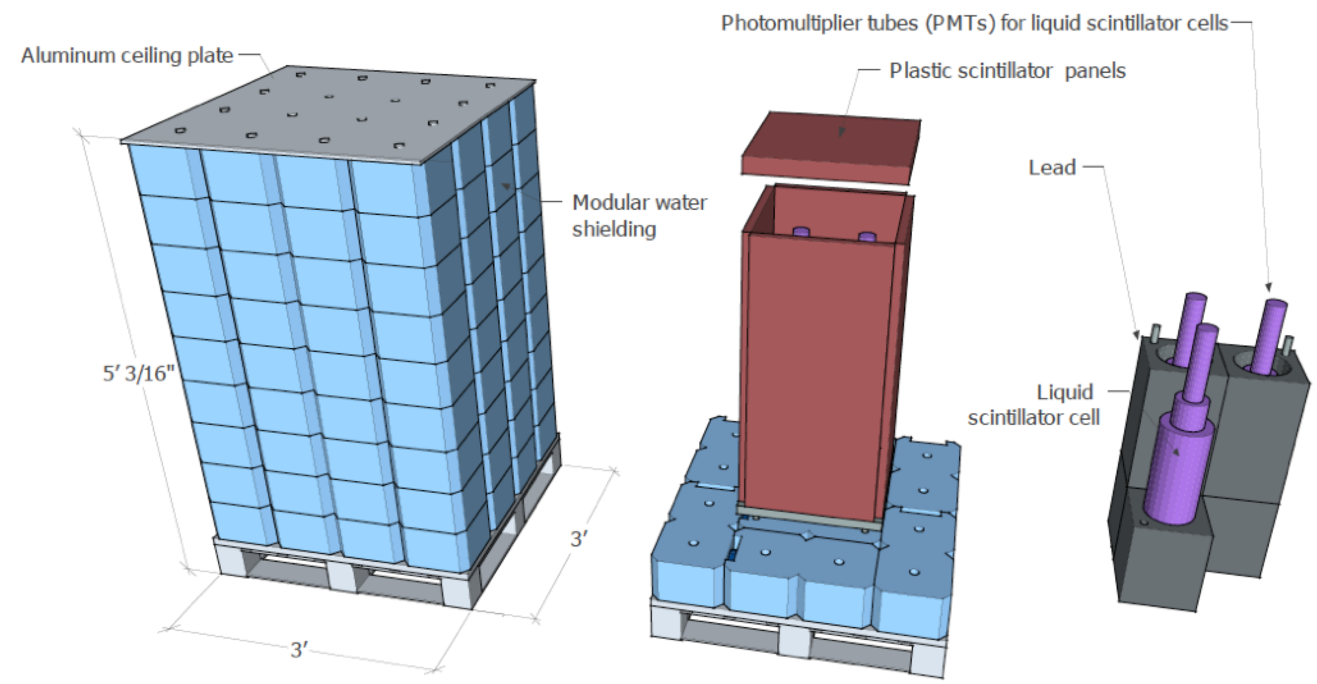


Neutrino-induced neutrons (NINs)

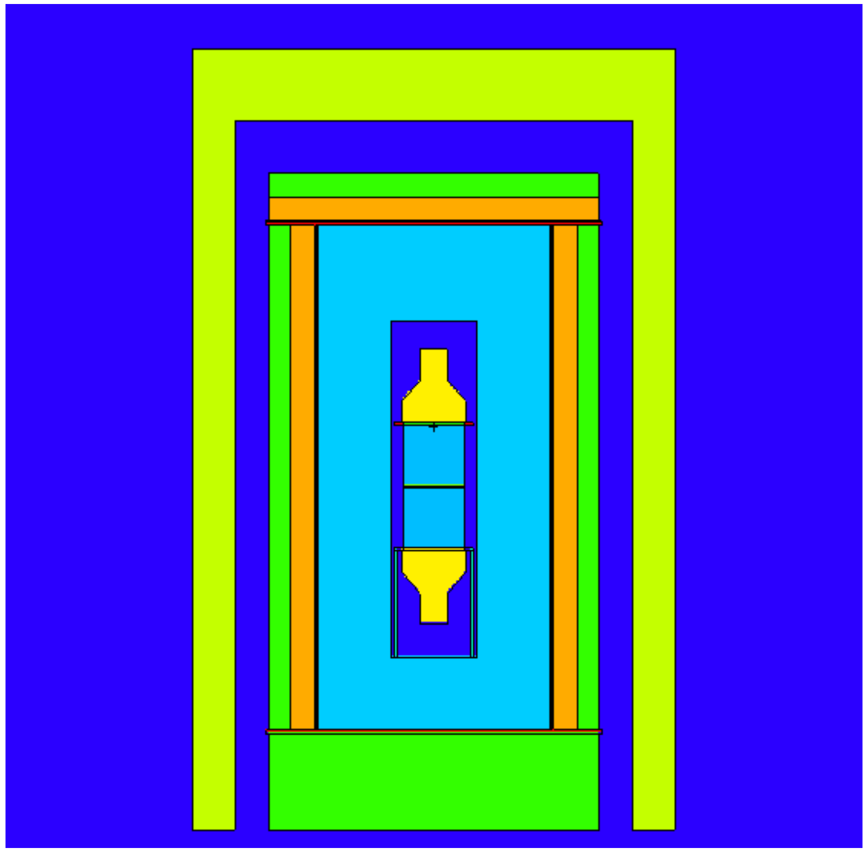
$$\nu_e + {}^{208}\mathrm{Pb} \Rightarrow {}^{208}\mathrm{Bi}^* + e^- \qquad \text{(CC)}$$
$$\Downarrow$$
$${}^{208-y}\mathrm{Bi} + x\gamma + yn,$$

$$\nu_x + {}^{208}\mathrm{Pb} \Rightarrow {}^{208}\mathrm{Pb}^* + \nu_x' \qquad \text{(NC)}$$
$$\Downarrow$$
$${}^{208-y}\mathrm{Pb} + x\gamma + yn.$$

- Dominant background for CEνNS measurement with naïve shielding configuration, but interesting physics of its own
    - Possible role in nucleosynthesis in certain astrophysical environments [1]
    - NIN production on Pb is the fundamental mechanism by which HALO intendeds to detect supernova neutrinos [2]
    - Process has never before been measured, considerable variation in theoretical predictions (~3x) [3]
- *In situ* measurements give rate limit, plus ongoing measurement of process with "neutrino cubes"



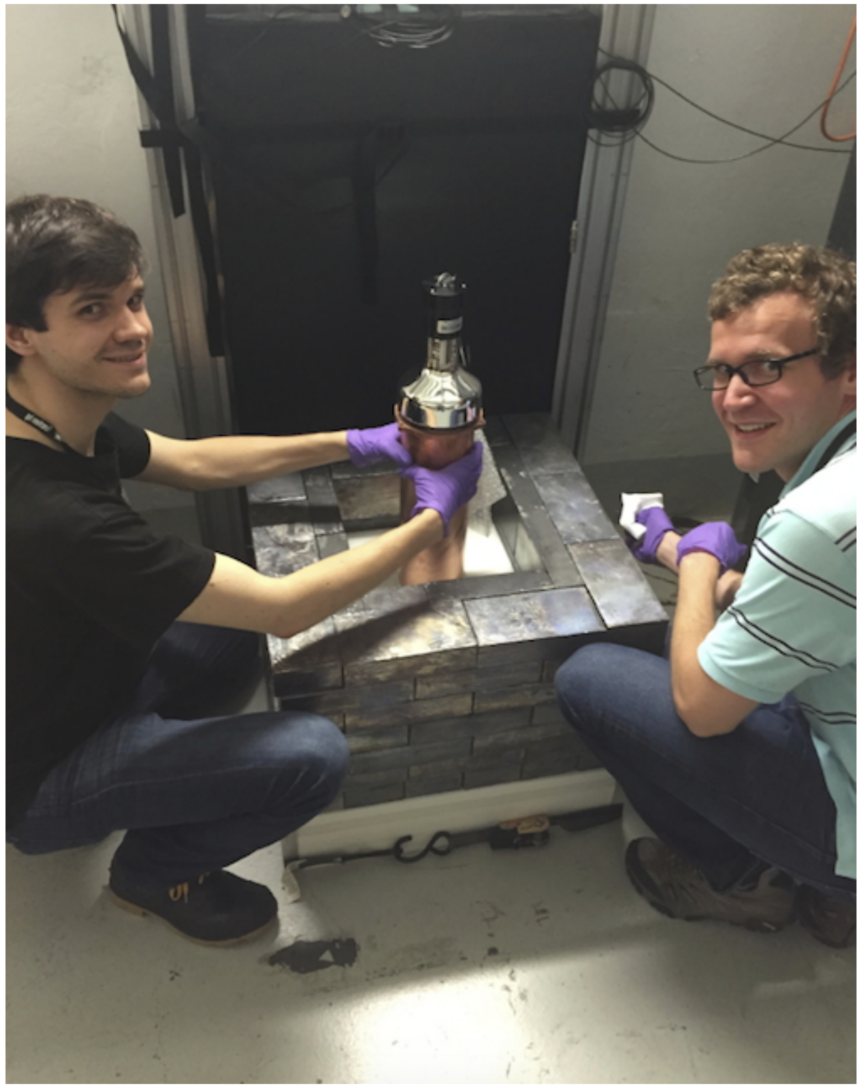
Neutrino cube design (top) and simulation geometry for *in situ* NIN measurement for CsI[Na] deployment (bottom)



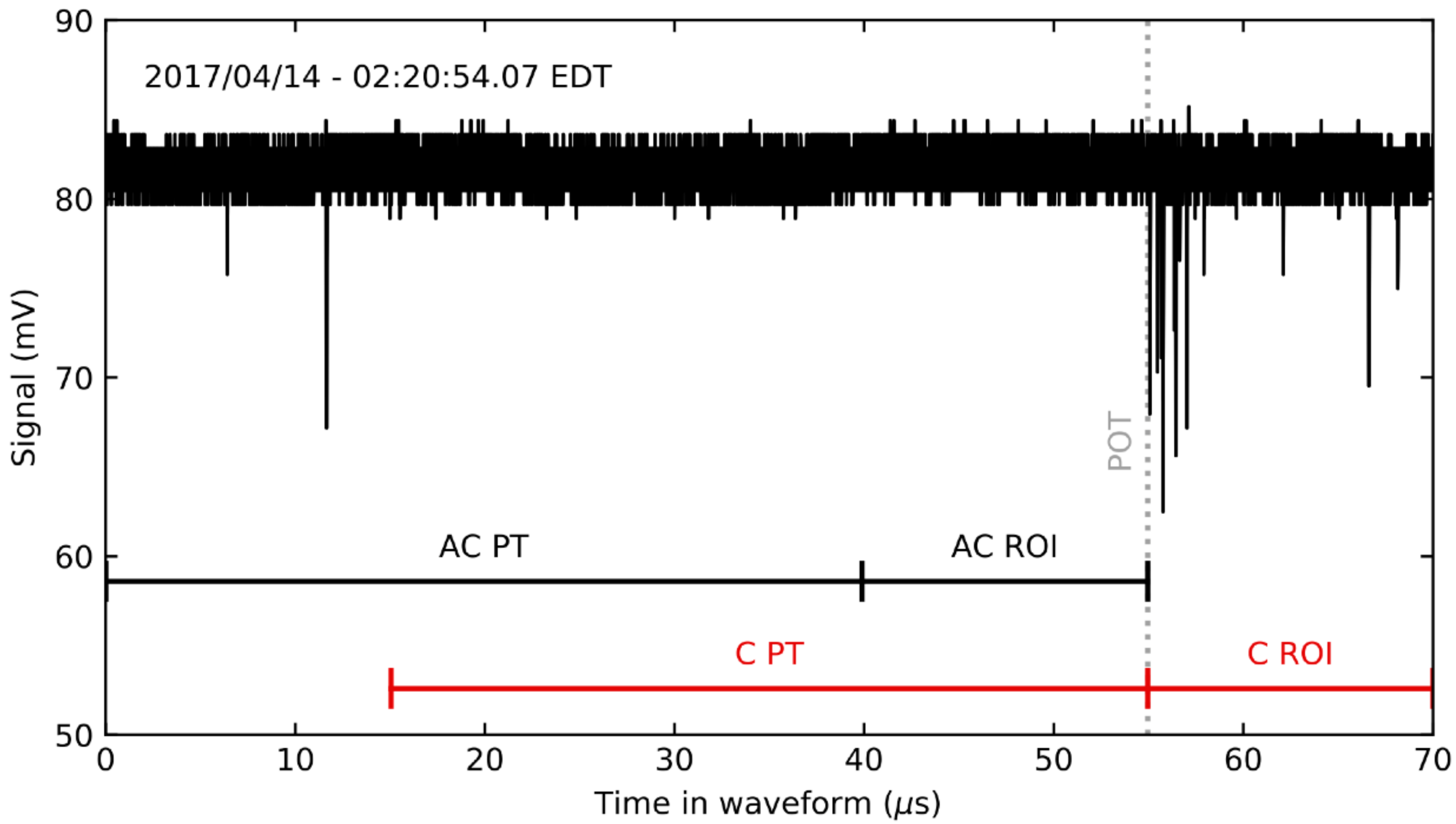
[1] Y-Z. Qian *et al.*, Phys. Rev. C 55 (1997)
[2] C.A. Duba *et al.* J. Phys. Conf. Series 136 (2008)
[3] C. Volpe, N. Auerbach, G. Colò, and N. Van. Giai, Phys. Rev. C 65 (2002)
NIN pathways from S.R. Elliott, Phys. Rev. C (2000)

CEνNS with CsI[Na]

Deployed to SNS in June 2015

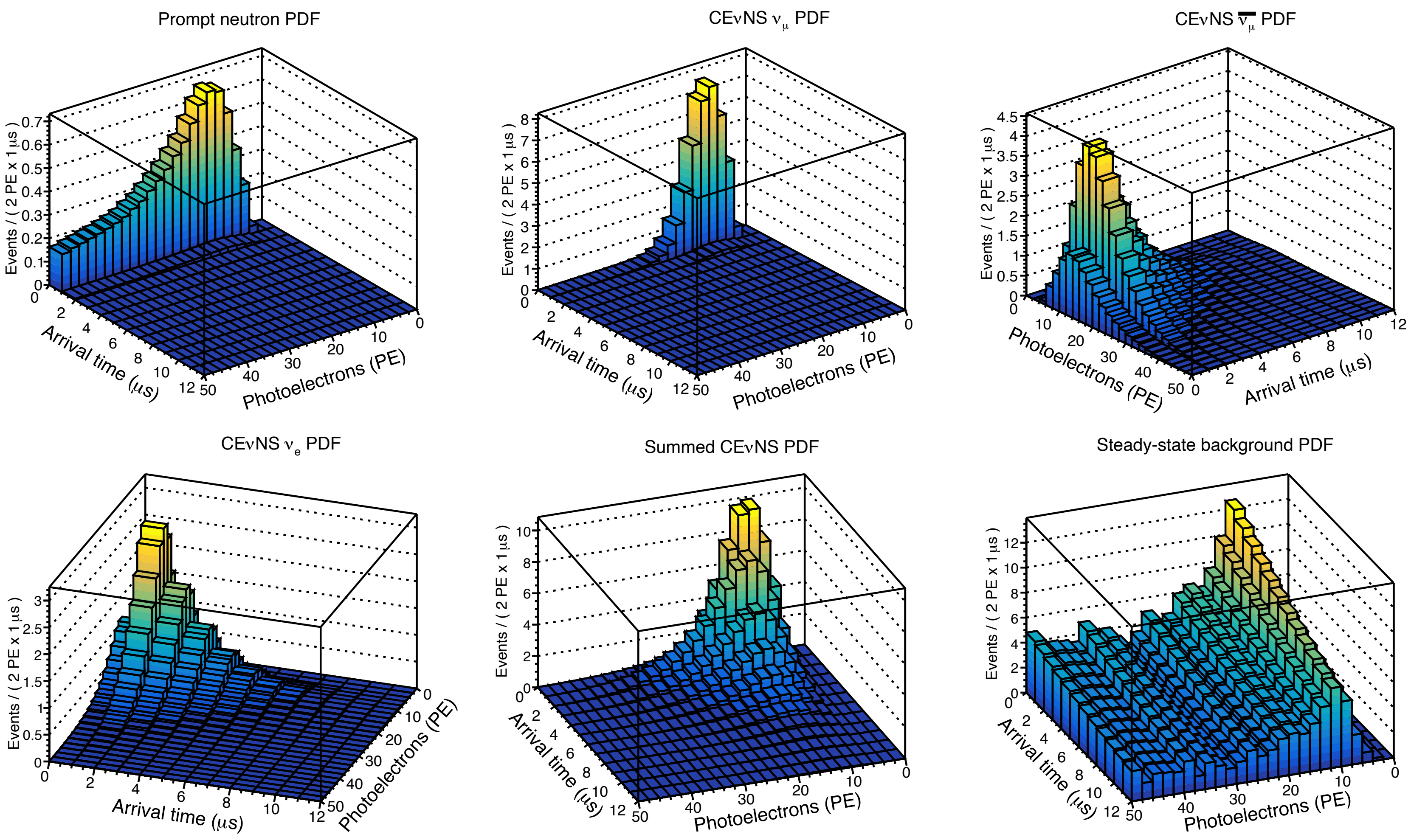


- 14.6-kg crystal made from low-background salts, encased in electroformed-copper can with PTFE reflector and synthetic silica window, surrounded by neutron and gamma shielding, including low-activity lead
- Development led by University of Chicago [1]
- Output of super-bialkali PMT with ~30% QE digitized for 70 μs, triggered by SNS timing signal



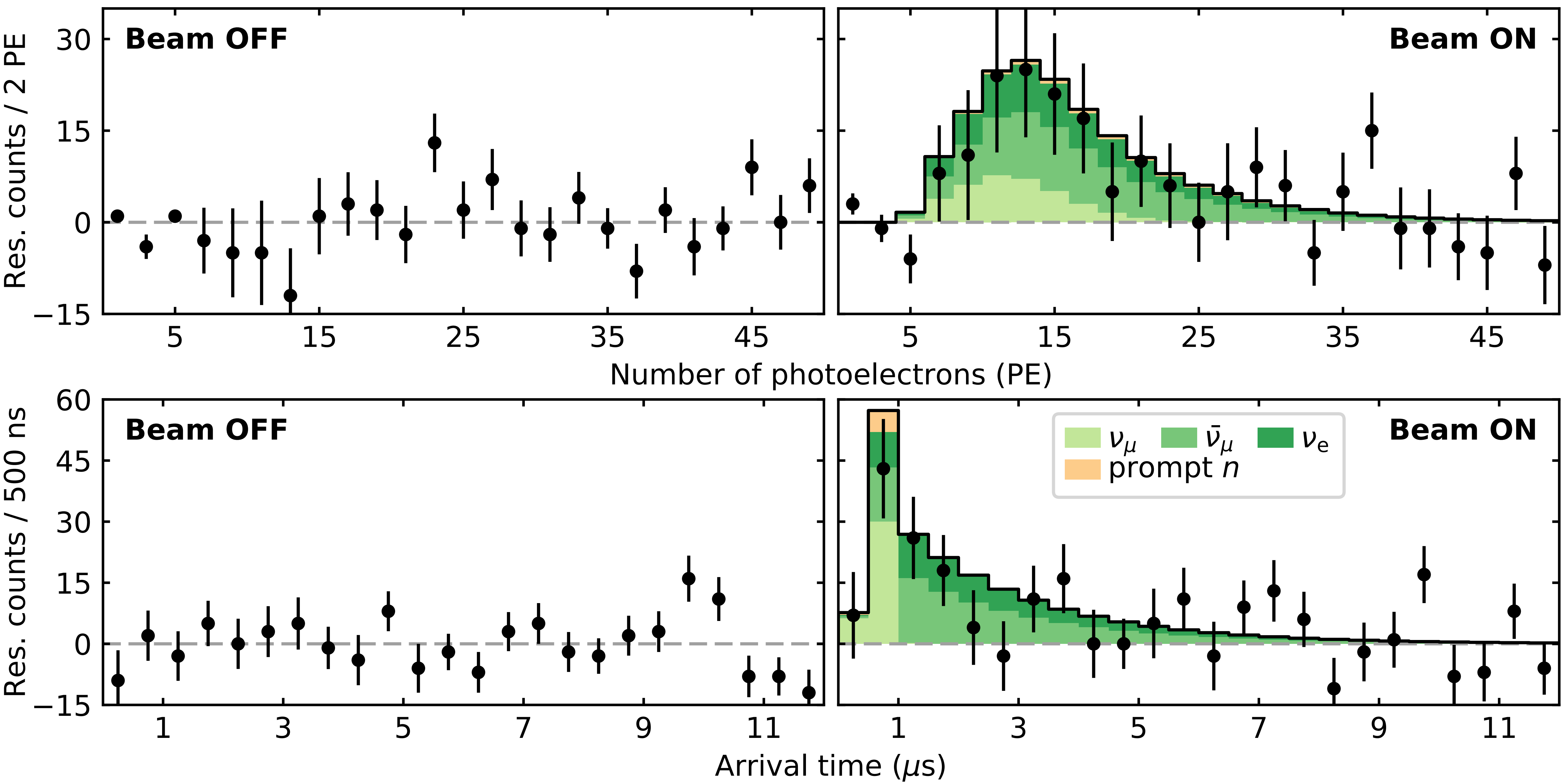
[1] J.I. Collar *et al.*, Nucl. Instrum. Meth. A 773 (2015)

Rate and shape estimates



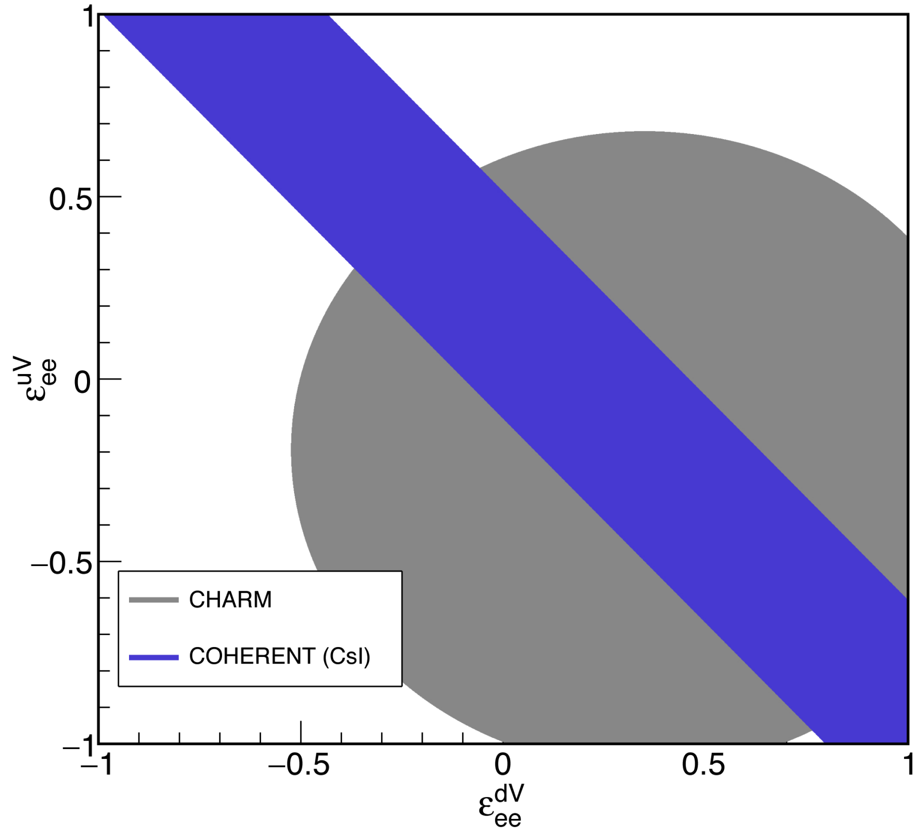
- Pulsed nature of beam facilitates analysis in time domain
- 2-D analysis (energy, time) makes use of all available information
- Ultimately performed binned 2-D profile likelihood analysis using PDFs shown here
  - Assumes Standard Model
  - Incorporates knowledge of detector response, analysis acceptance, etc

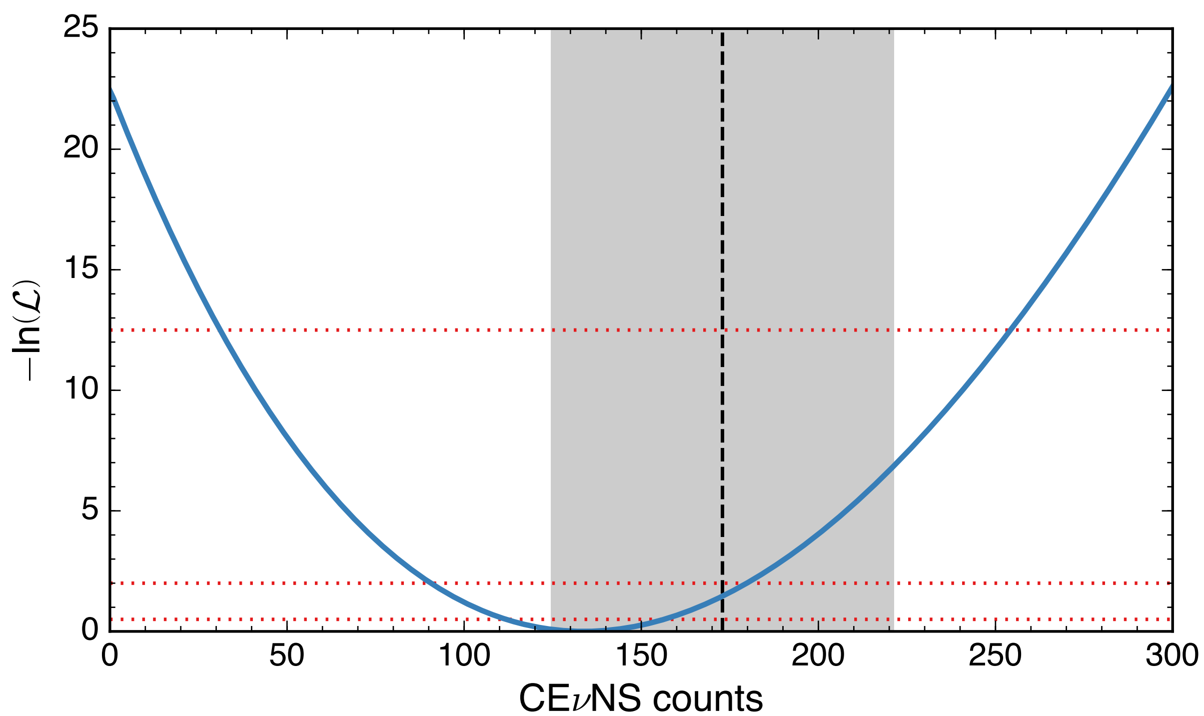
SM prediction and data



Results

- Beam exposure: ~6 GWhr, or ~1.4 × 10^{23} protons on target (0.22 grams of protons)
- Analyzed as a simple counting experiment
  - 136 ± 31 counts
- 2-D profile likelihood analysis
  - 134 ± 22 counts, within 1-σ of SM prediction of 173 ± 48
  - Null hypothesis disfavored at 6.7-σ level relative to best-fit number of counts
- Able to further constrain some NSI parameters



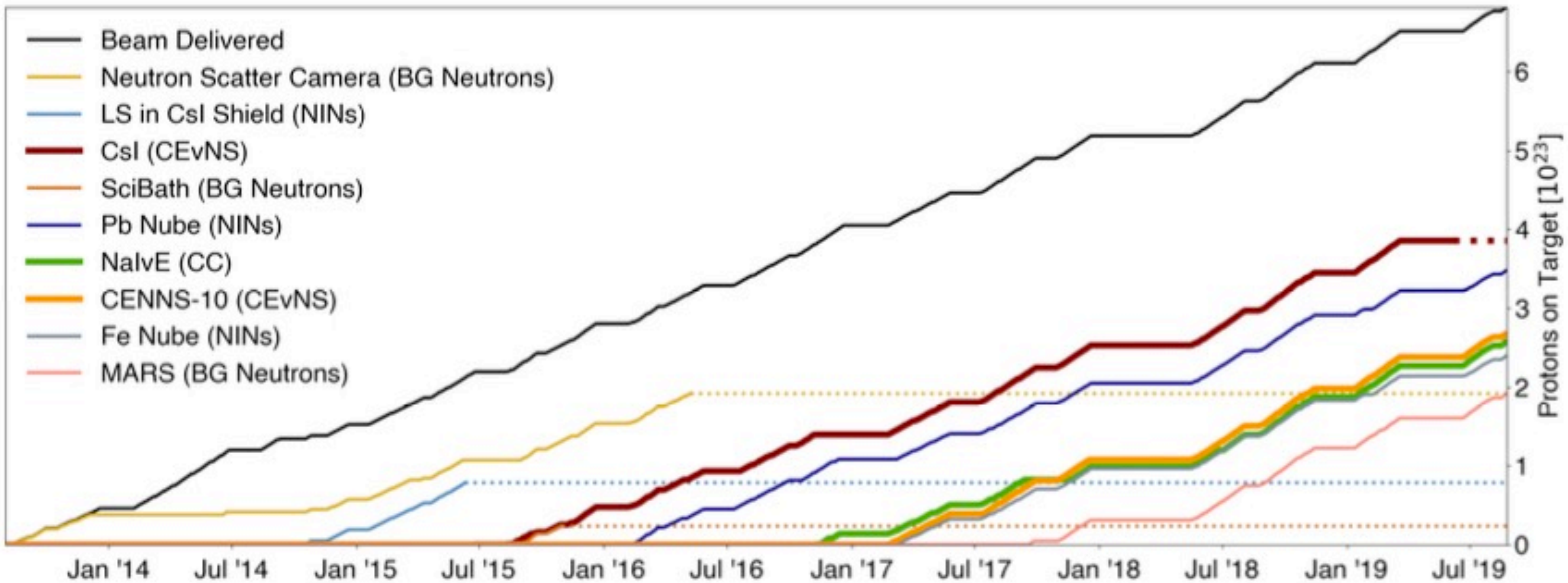


Dominant systematic uncertainties on predicted rates

Quenching factor	25%
ν flux	10%
Nuc. form factor	5%
Analysis acceptance	5%

D. Akimov *et al.* (COHERENT), Science (2017) 10.1126/science.aao0990

Since the first observation…

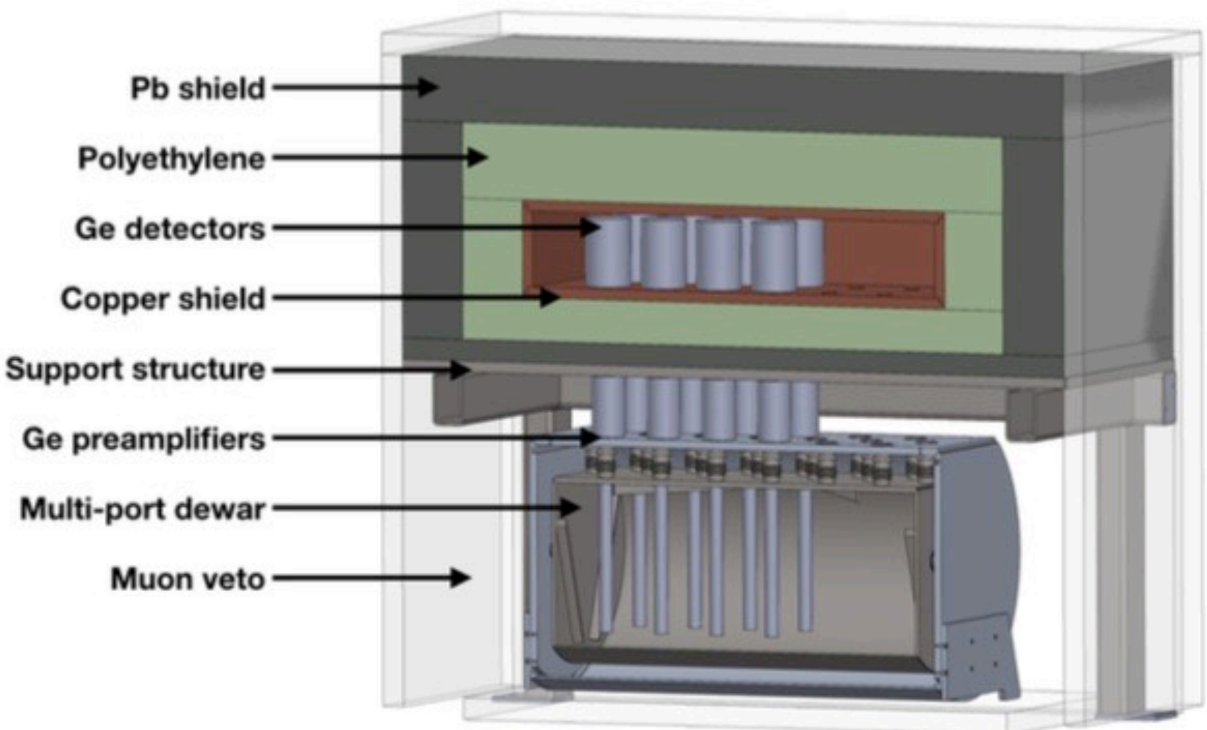


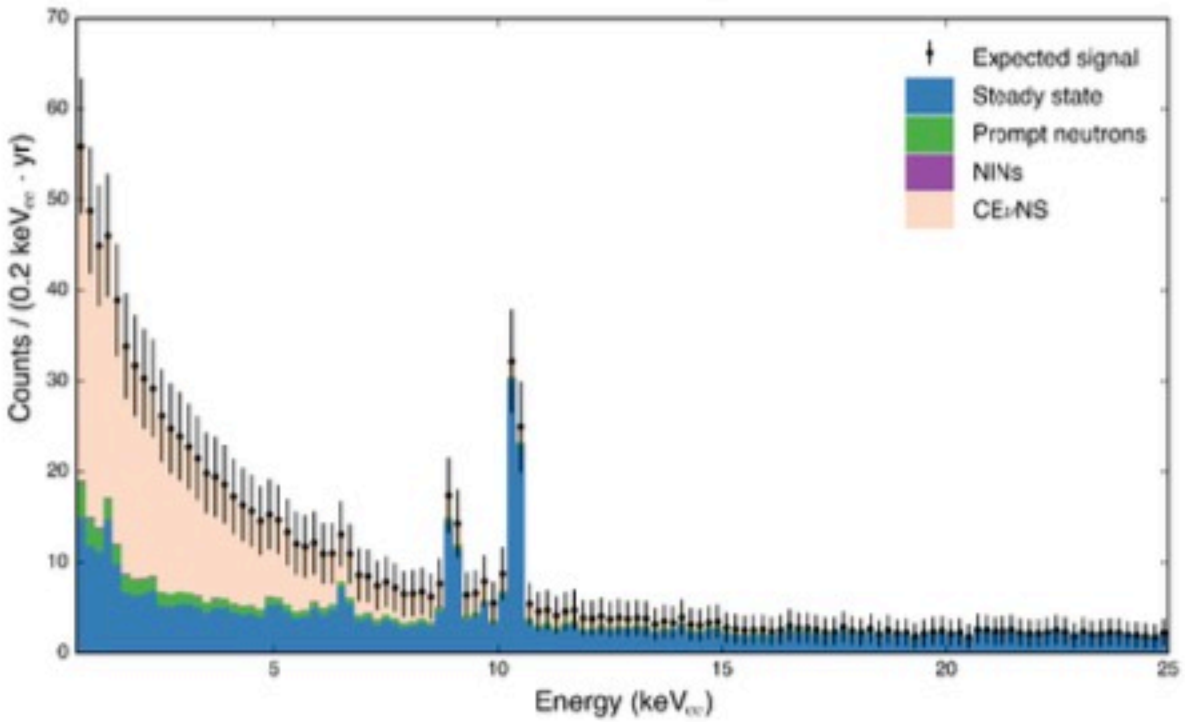
- CsI[Na] data collection continued
  - Decommissioned June 2019
  - Final result should have ~2x statistics
- LAr data collection / upgrades
- Non-CEvNS efforts
  - Beam-related neutron backgrounds
  - NINs

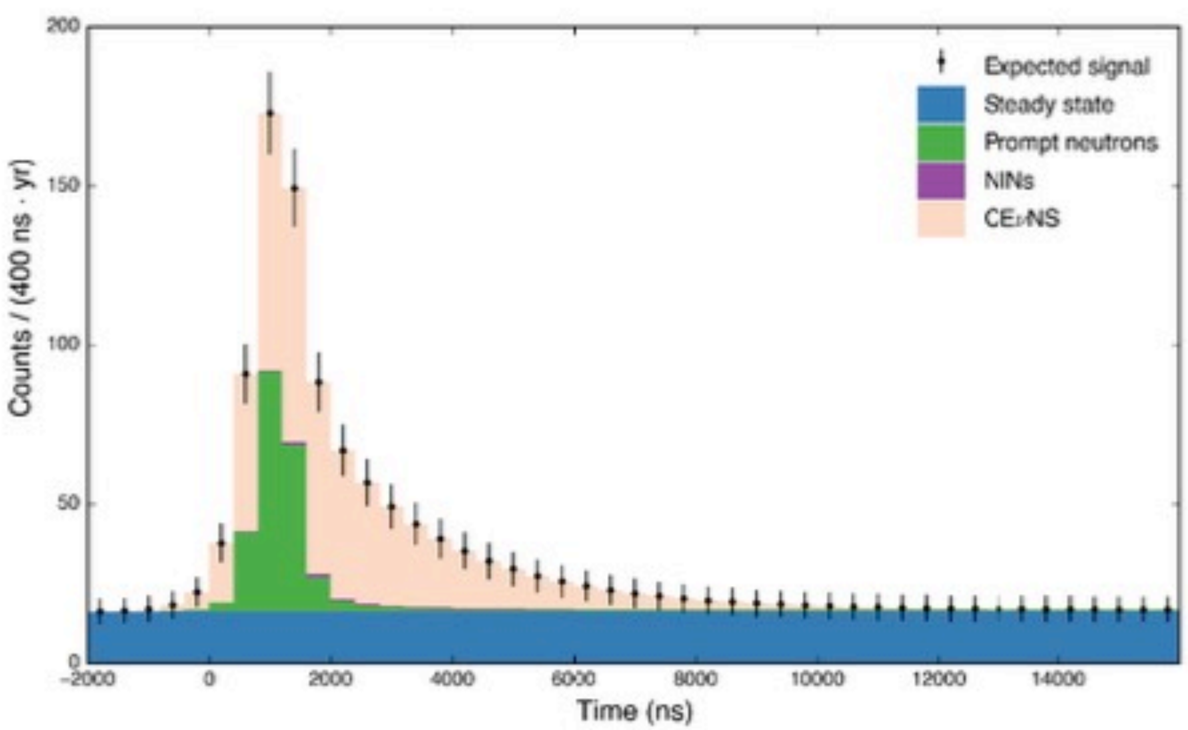
D. Akimov *et al.*, Science (2017) 10.1126/science.aao0990

Ge @ COHERENT

- MRI funding to support deployment of 16-kg Ge PPC detectors to SNS
    - Effort led by NCSU/Duke/NCCU
    - < 3 keVnr threshold
- Expect 500-600 CEvNS events/year
- Targeting deployment in 2020







CENNS-10 @ COHERENT

- CENNS-10 detector originally developed and built at FNAL as part of CENNS project
- Moved to SNS late 2016
- Original threshold ~100 keVnr
  - Not sensitive to CEvNS, but could provide valuable insight into backgrounds etc

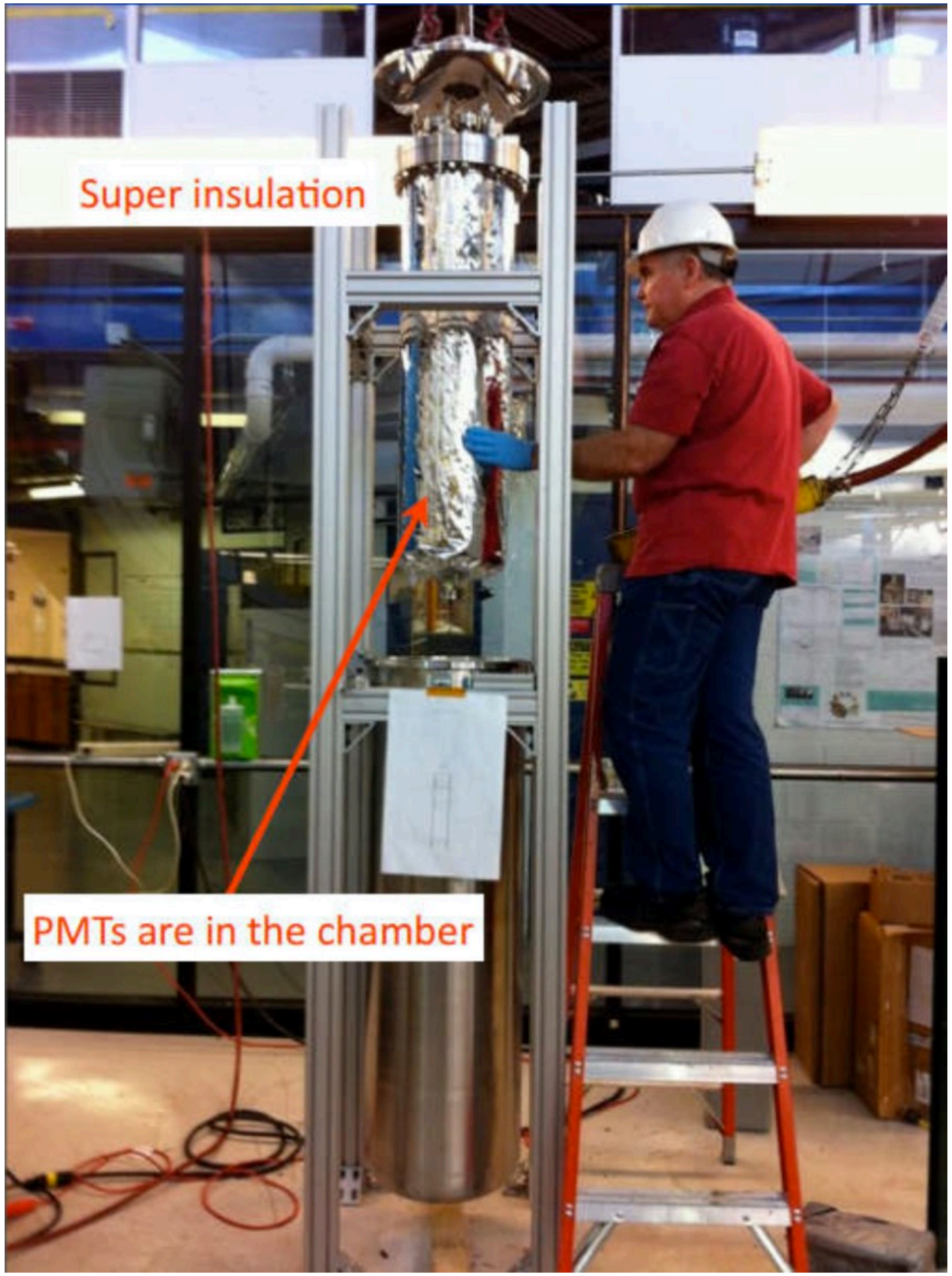
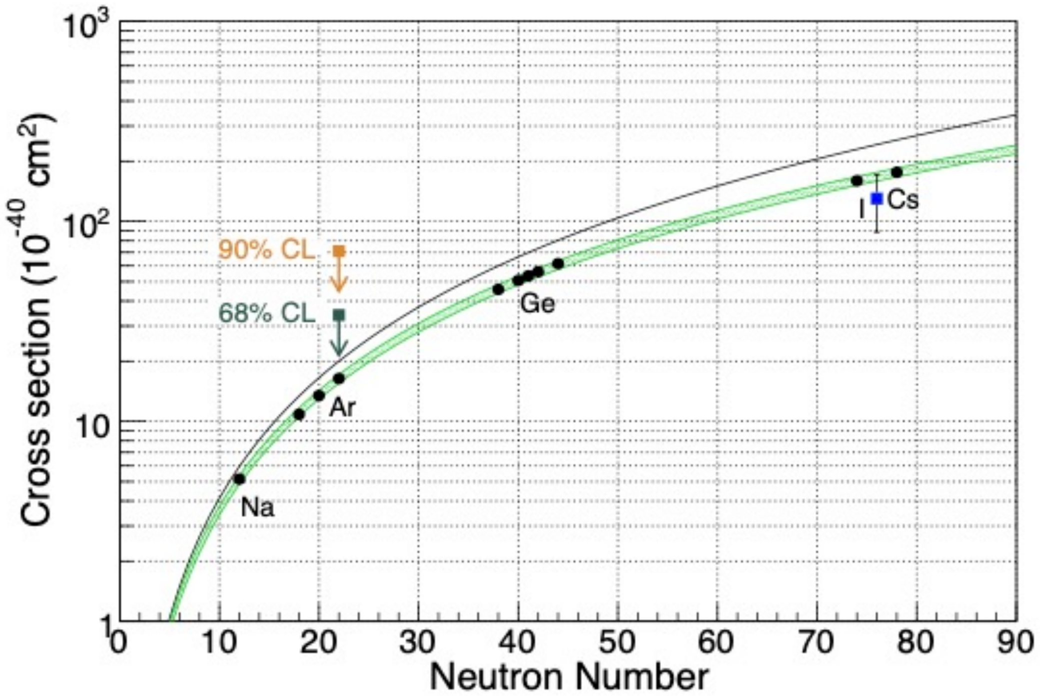
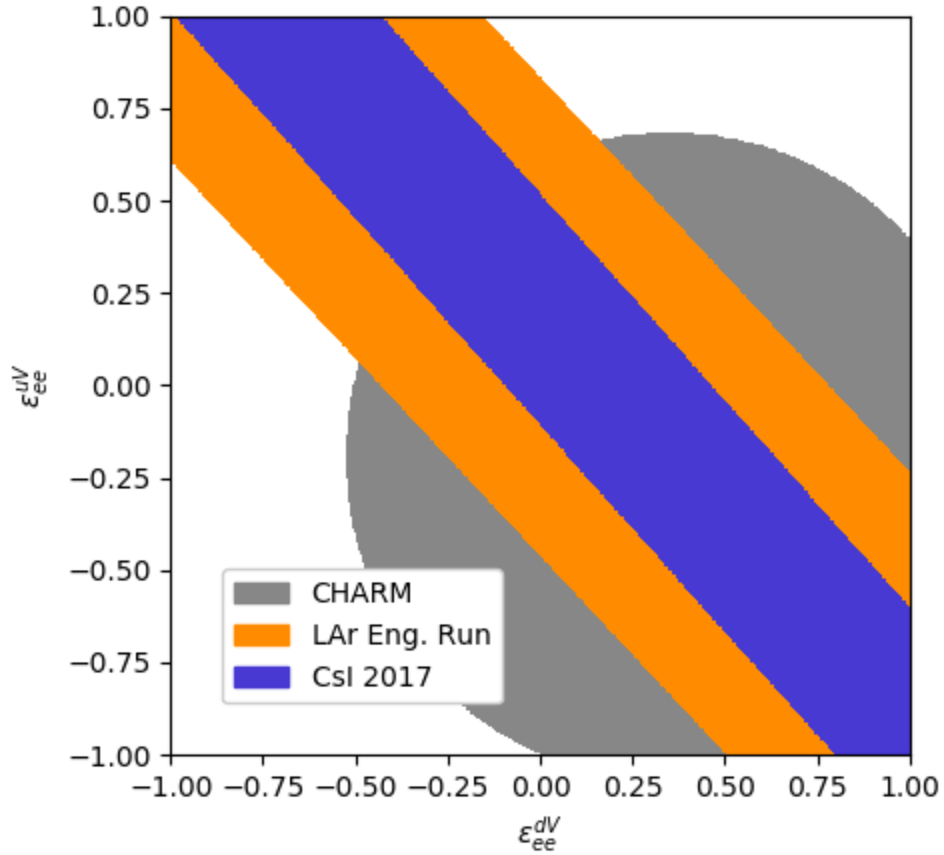


Photo of Andy Lathrop (FNAL) with CENNS-10 during assembly at FNAL
(Photo from talk by R. Tayloe (IU), Underground Argon Workshop)

CENNS-10 @ COHERENT

- First limit published recently in Phys. Rev. D (10.1103/PhysRevD.100.115020; Editors' suggestion)!
- Even with limited statistics, light yield, etc., constraints are able to be determined for certain NSI parameters (though not improving on previous COHERENT limits)
- PhD thesis (Indiana University) for Matthew Heath

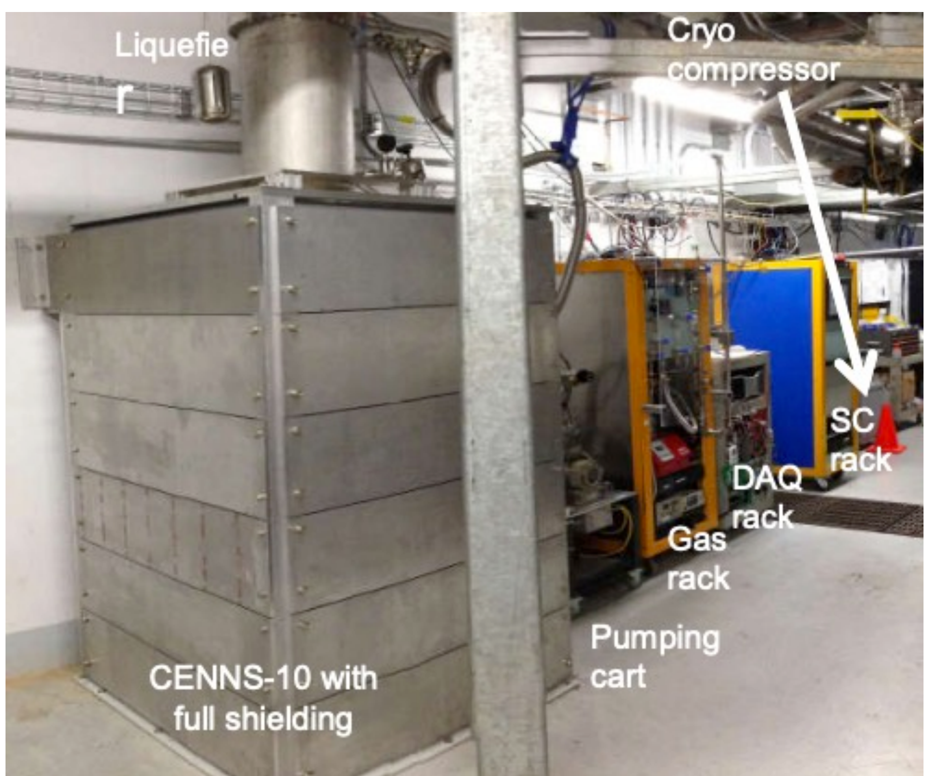




D. Akimov *et al.* (COHERENT), Phys. Rev. D (2019) 10.1103/PhysRevD.100.115020

CENNS-10 upgrades and physics run

- Several improvements made to CENNS-10 detector to boost sensitivity
  - Improved light collection
  - Added shielding
- FNAL W&C 10 Jan, 2020
  - Make of this what you will…



Joint Experimental-Theoretical Physics Seminar

Regular seminars are **Fridays at 4:00 p.m. in Wilson Hall, One West**.
Special dates or rooms are given below.

Please contact Roni Harnik for more information.

A live video stream is sometimes available, check this link.

Show 50 entries

Search:

Event date	Title	Speakers	Links
Dec. 13	seminar postponed (date open)		
Jan. 10	New Results from COHERENT	Jacob Zettlemoyer, Indiana University	
Jan. 17	TBD	Carlos Arguelles Delgado, MIT	
Jan. 24	Higgs-Yukawa Universality	Chris Hill, Fermilab	
Feb. 14	New Results from CMS		
Feb. 21	New Result from ArgoNeuT		
Feb. 28	New Results from MINERvA		
April 10	New Results from CMS		

Screenshot from https://theory.fnal.gov/jetp/ (12 Dec 2019)

Connections to numerous areas of nuclear and particle physics

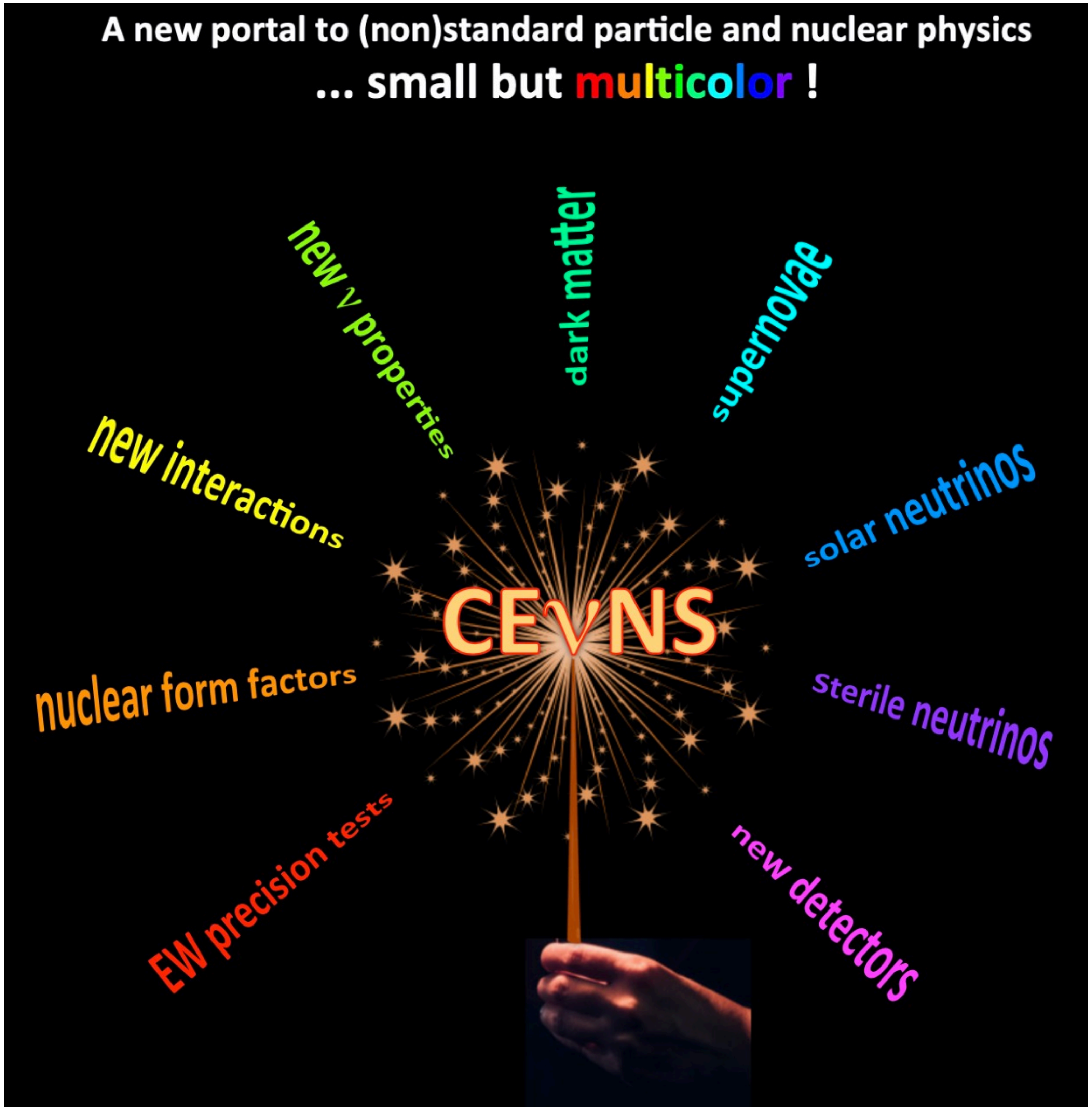
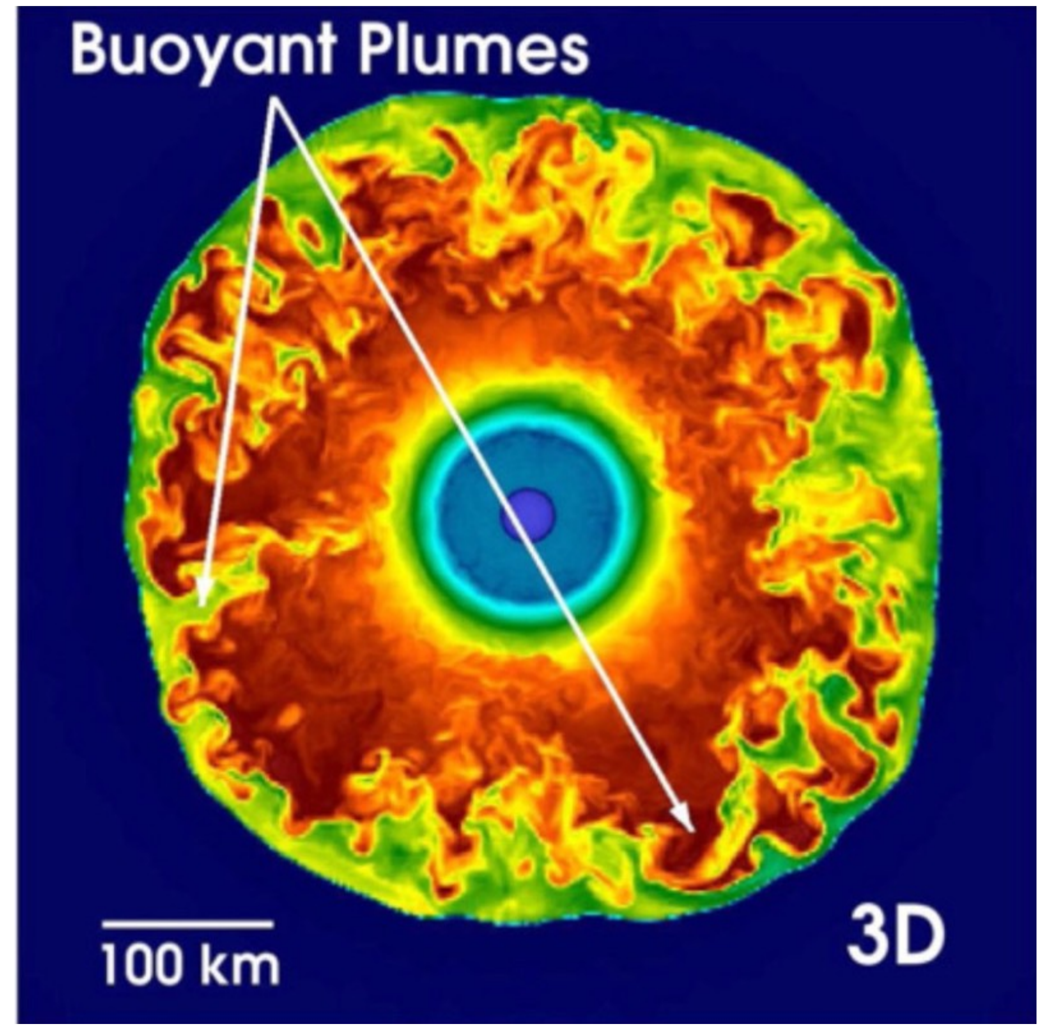


Image from E. Lisi, Neutrino 2018, 10.5281/zenodo.1286745

CEνNS and supernovae

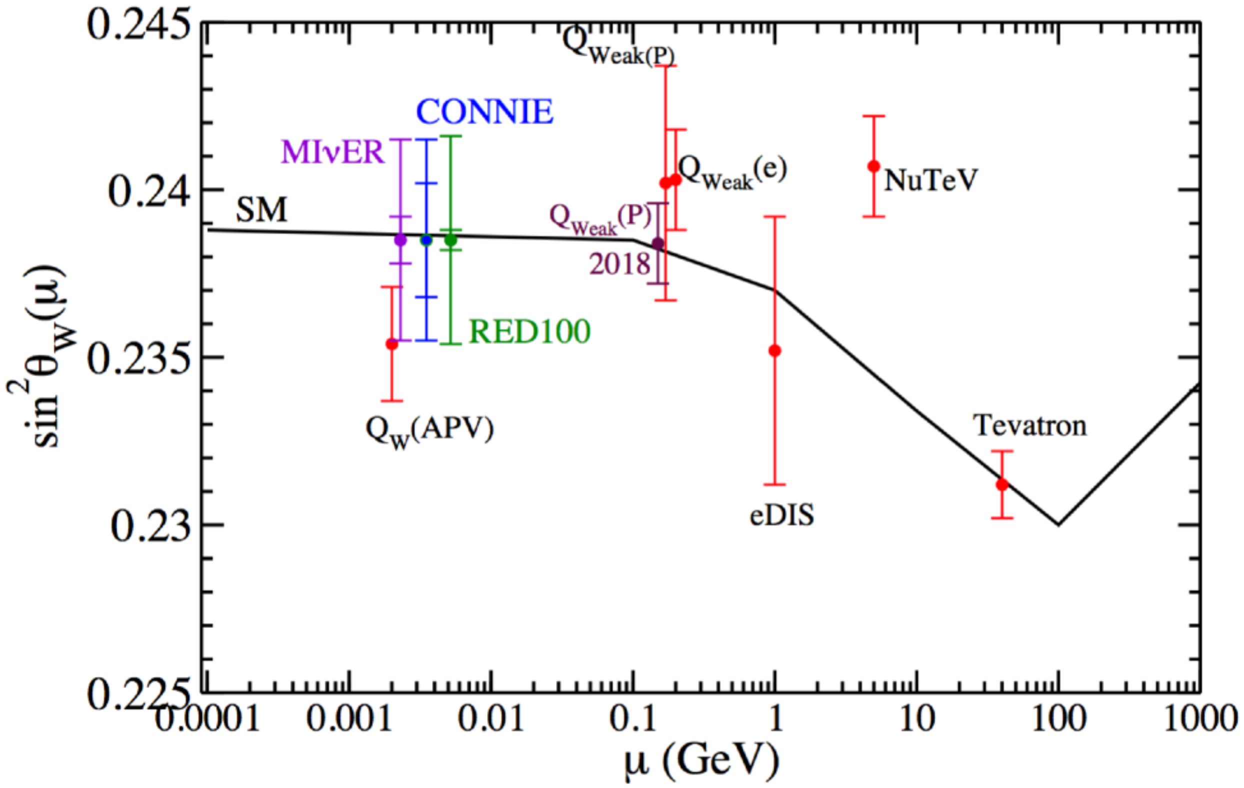
- Freedman immediately recognized CEνNS could be significant in core-collapse supernovae
  - ~99% of radiated energy, ~10^{53} ergs, carried in ~10^{58} neutrinos
  - The comparatively large CEνNS cross section presents a viable way to couple neutrino flux to stellar matter
- Supernova models generally failed to explode, but neutrinos could help
  - "Delayed shock" mechanism, where neutrinos re-energize the explosion, persists for a long time as a possible explanation [1]
- Neutrino opacity in certain regions may still be significantly influenced by CEνNS [2,3]
- CEνNS also presents a way to *detect* the neutrinos from supernovae [4]
  - Neutrinos can possibly carry information otherwise unavailable
  - CEνNS-based detectors could see ~few events per ton for a CCSNe at 10 kpc [4]

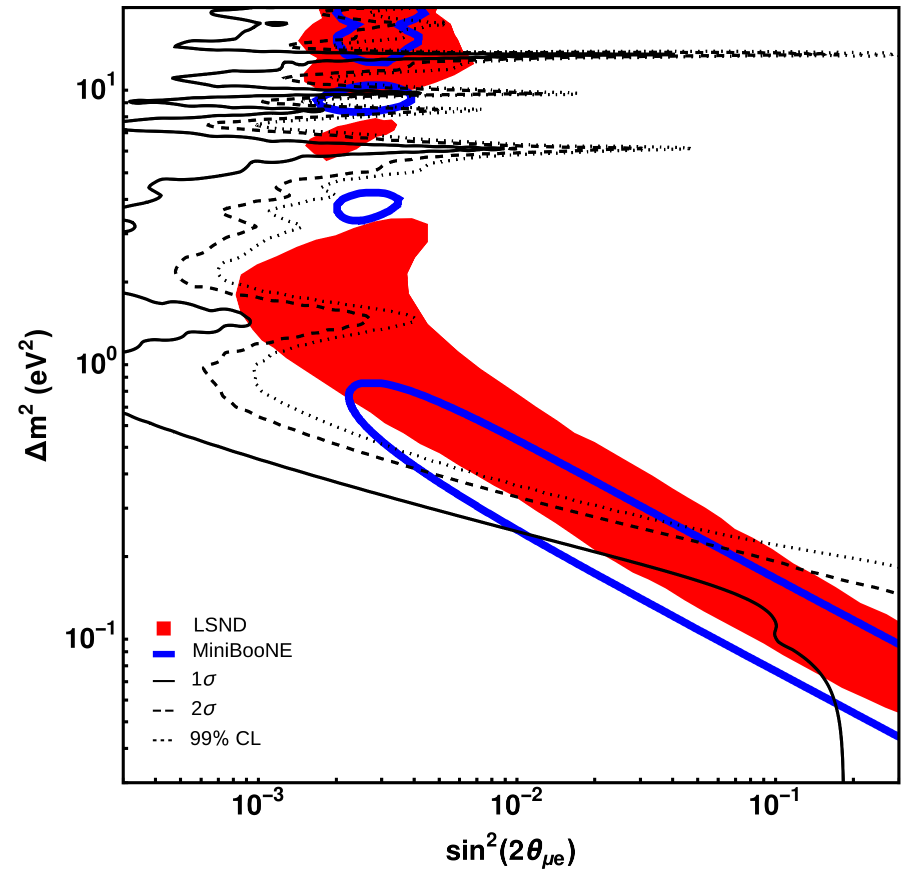


[1] H.A. Bethe, Rev. Mod. Phys 62 (1990)
[2] K.G. Balasi K. Langanke, G. Martínez-Pinedo, Prog. Part. Nucl. Phys. 85 (2015),1503.08095
[3] S.W. Bruenn, A. Mezzacappa, Phys. Rev. D 56 (1997)
[4] C. Horowitz *et al.*, Phys. Rev. D 68 (2003)
Image from J.W. Murphy, J.C. Dolence, A. Burrows, Ap. J. 771 (2013)

Physics from CEνNS

$$\frac{d\sigma}{dT} = \frac{G_F^2}{2\pi} M \left[2 - \frac{2T}{E_\nu} + \left(\frac{T}{E_\nu}\right)^2 - \frac{MT}{E_\nu^2}\right] \frac{Q_W^2}{4} \left(F(Q^2)\right)^2$$





Weak mixing angle - Unique probe of $Q_W{}^2$ at a unique Q in a region sensitive to dark-Z boson models [1,2]

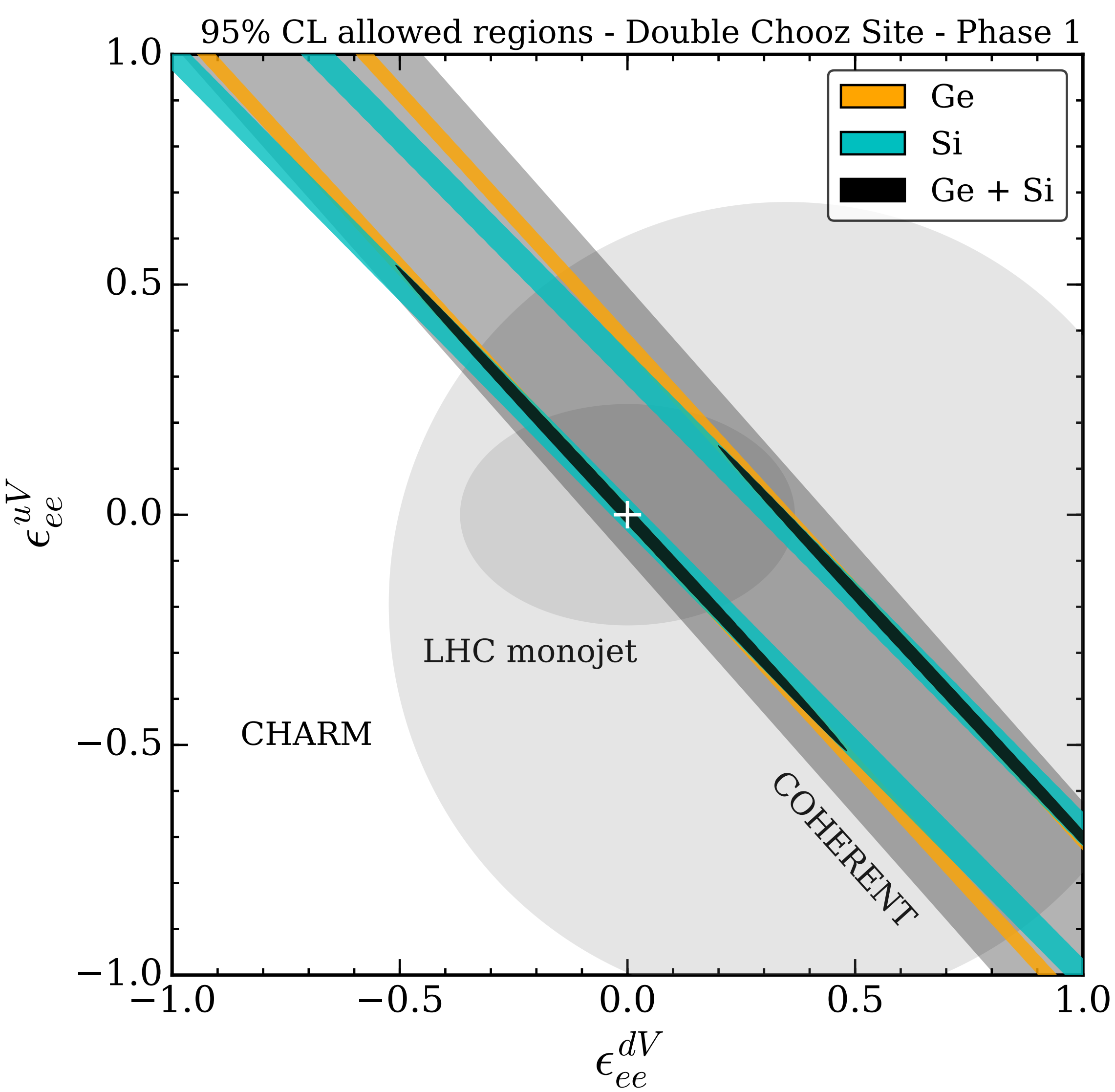
Neutral-current sterile neutrino search - all-flavor disappearance experiment [3,4] could test, e.g., LSND & MiniBooNE [5]

[1] B.C. Cañas *et al.*, 1806.01310
[2] H. Davoudiasl *et al.*, Phys. Rev. D 89 (2014)
[3] A.J. Anderson *et al.*, Phys. Rev. D 86 (2012)
[4] B.C. Cañas *et al.*, Phys. Lett. B (776) (2018), 1708.09518
[5] C. Blanco, D. Hooper, P. Machado, 1901.08094

Left figure from [1], right from [5]

Physics from CEνNS

$$Q_W^2 \to Q_{\rm NSI}^2 = 4\left[N\left(-\frac{1}{2} + \epsilon_{ee}^{uV} + 2\epsilon_{ee}^{dV}\right) + Z\left(\frac{1}{2} - 2\sin^2\theta_W + 2\epsilon_{ee}^{uV} + \epsilon_{ee}^{dV}\right)\right]^2$$
$$+ 4\left[N(\epsilon_{e\tau}^{uV} + 2\epsilon_{e\tau}^{dV}) + Z(2\epsilon_{e\tau}^{uV} + \epsilon_{e\tau}^{dV})\right]^2 .$$



Non-standard neutrino interactions - Additional terms added to SM lagrangian, with the effect of modifying the weak charge. Thus, this is manifested as an overall scaling of the expected CEνNS cross section

CEνNS shows dependence on both non-universal and flavor-changing neutral currents.

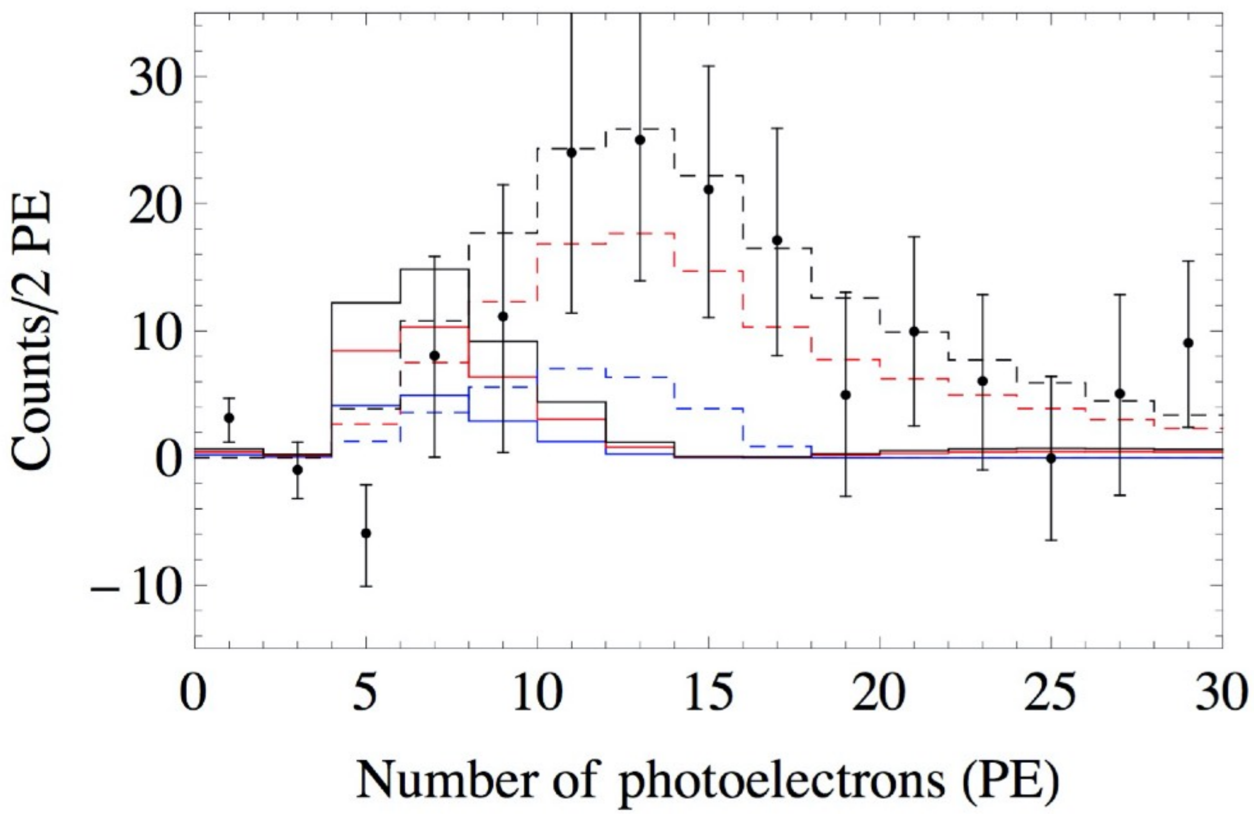
Targets with different *N/Z* ratios provide degeneracy-breaking strength in *u* and *d* couplings shown in figure at left

[1] J. Barranco *et al.*, Phys. Rev. D 76 (2007)
[2] J. Billard, J. Johnston, B. Kavanagh, arXiv:1805.01798

Figure and Eq from [2]

Physics from CEνNS

$$Q^2_{\alpha,\mathrm{NSI}} = \left[Z\left(g_p^V + \frac{3g^2}{2\sqrt{2}G_F(Q^2+M_{Z'}^2)} \right) + N\left(g_n^V + \frac{3g^2}{2\sqrt{2}G_F(Q^2+M_{Z'}^2)} \right) \right]^2$$



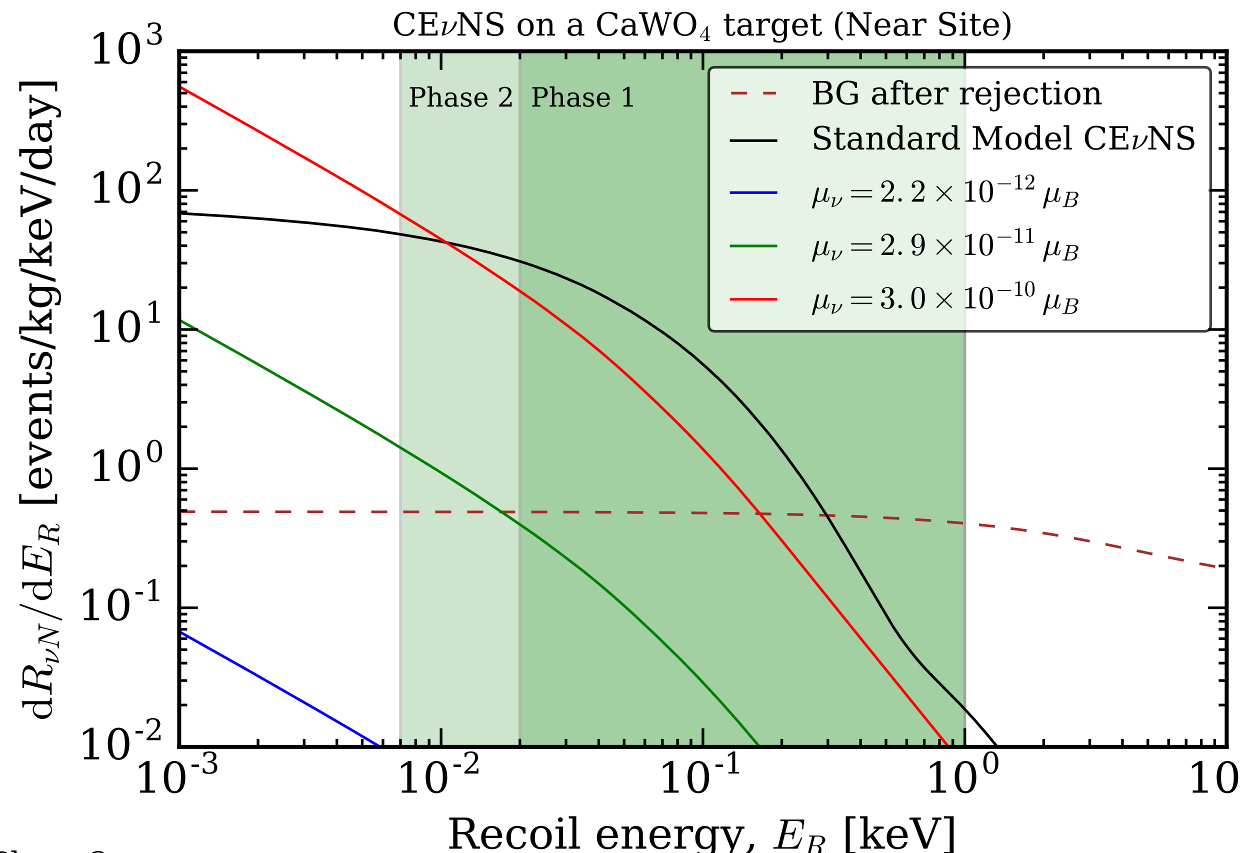
- With a light mediator, the NSI contributions are manifested somewhat differently
- Weak charge still modified, but now there is a Q^2 dependence
    - Result is a spectral distortion, not an overall rate scaling [1]

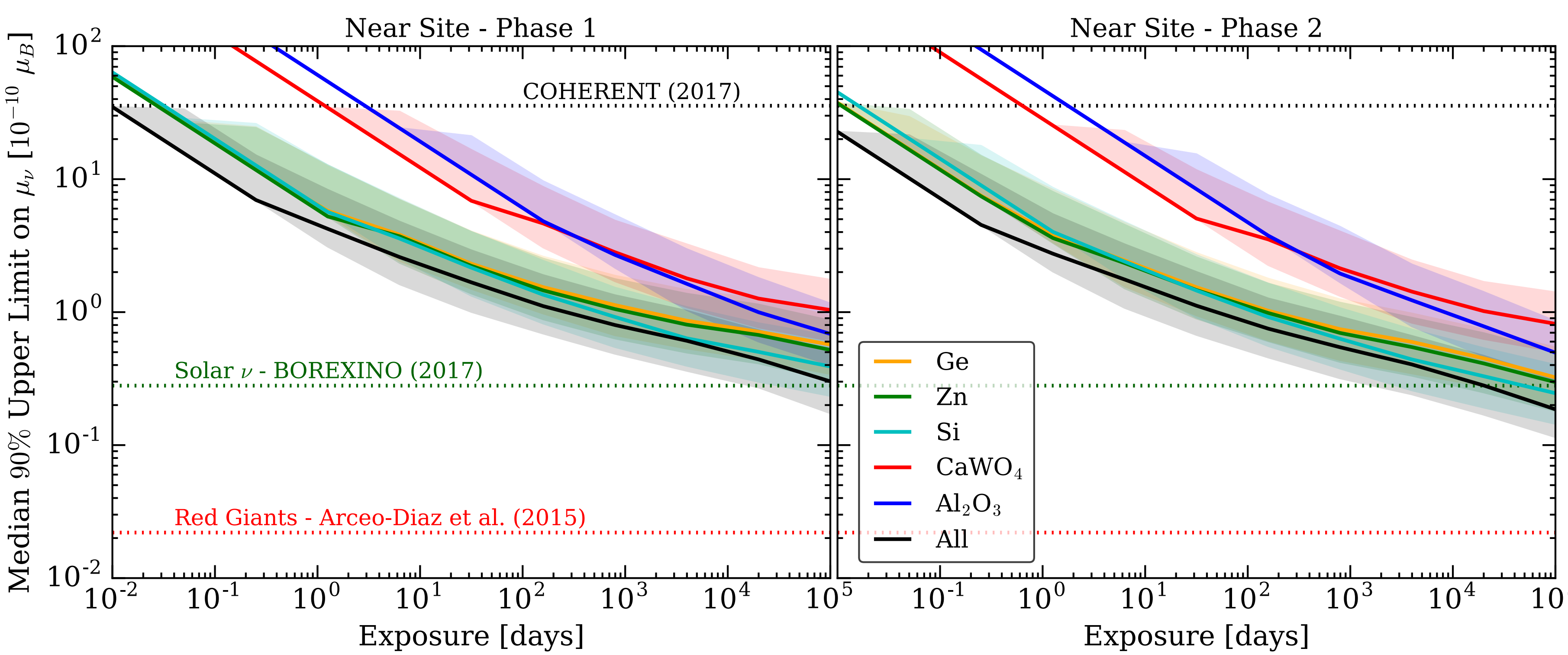
[1] J. Liao and D. Marfatia, 1708.04255
Eq. and Fig. from [1]

Physics from CEνNS

Fundamental properties of neutrinos - sensitivity to neutrino electromagnetic properties (e.g., magnetic moment) [1,2] *and* lift degeneracy of "dark side" solution to θ_{12} that would complicate mass-order determination from oscillation experiments [3]

Plots show predictions for contributions from neutrino magnetic moment and sensitivity for specific experimental cases



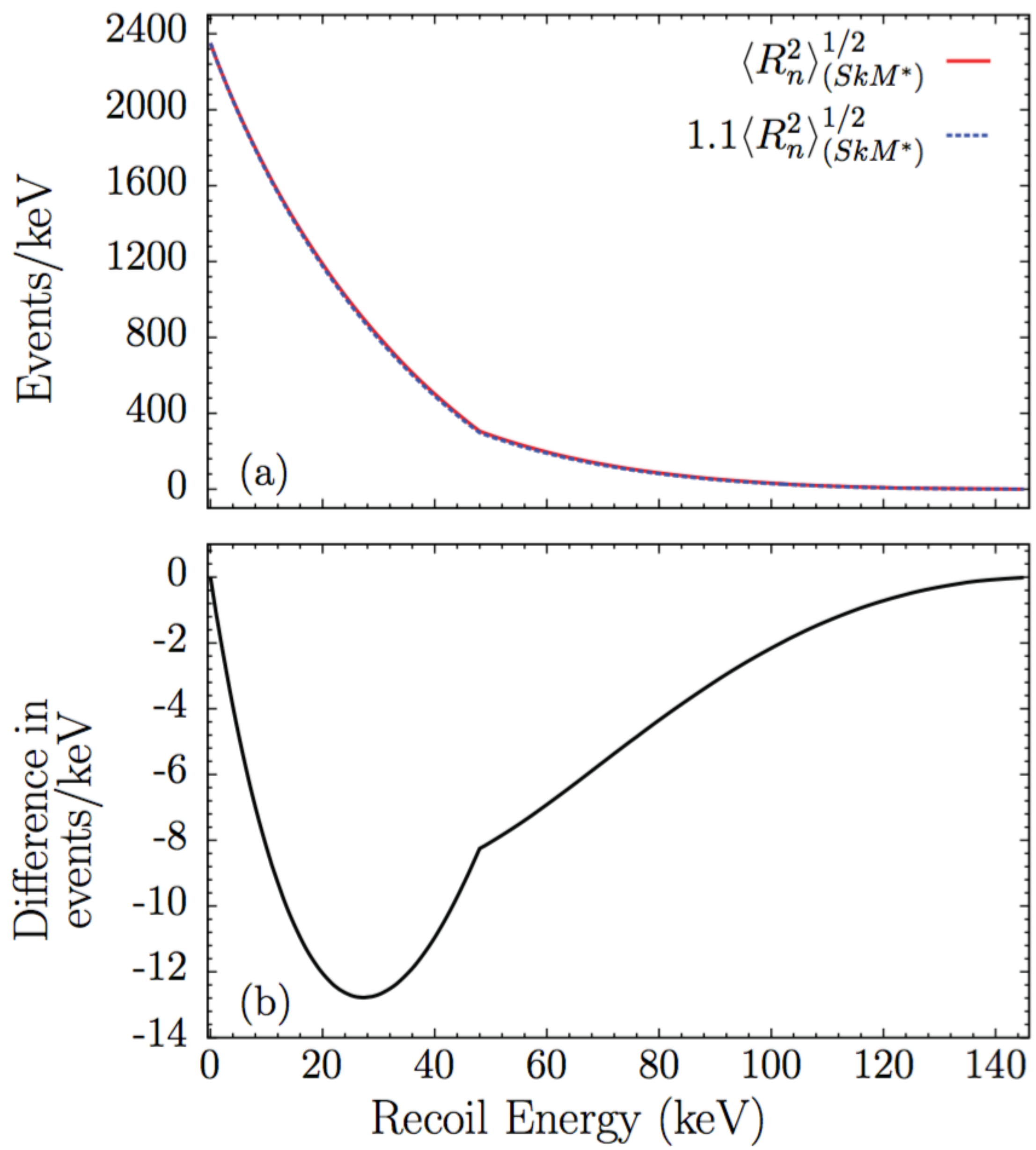


Magnetic moment introduces spectral change at very-low energy recoils

Existing limits from BOREXINO and red giant cooling are hard to match

[1] K. Scholberg, Phys. Rev. D 73 (2006)
[2] J. Billard, J. Johnston, B. Kavanagh, arXiv:1805.01798
[3] P. Coloma *et al.*, Phys. Rev. D 96 (2017)
Figs from [2]

CEνNS as a tool for nuclear physics



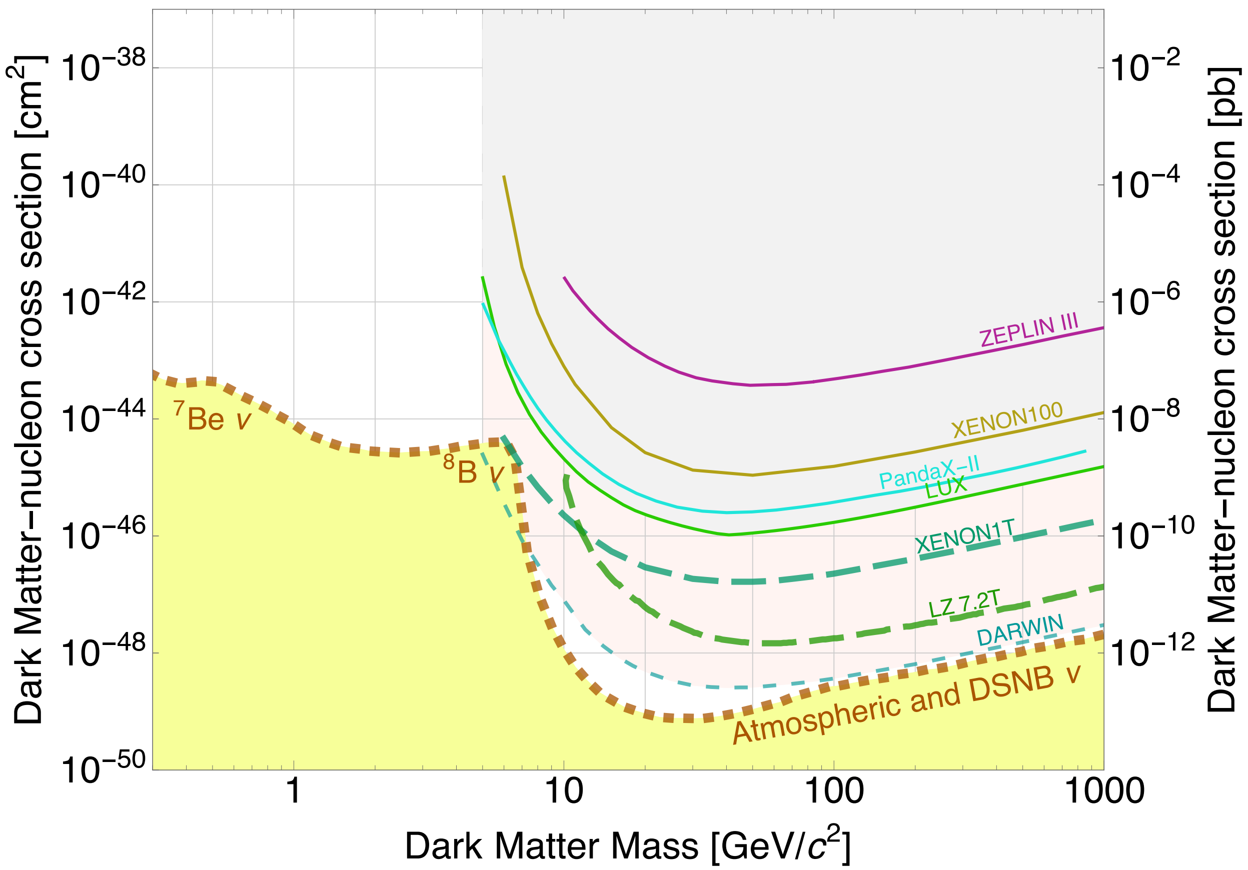
- CEνNS is sensitive to the distribution of neutrons in nuclei
  - Can be used to measure this distribution [1], which is otherwise very challenging
  - Won't be competitive with purpose-built experiments (e.g., PREX and CREX) in foreseeable future, but more flexible - can (somewhat) easily measure neutron distribution in different nuclei
  - This input can refine nuclear structure models and improve understanding of neutron star EoS [2]
- CEνNS-based monitoring of nuclear reactors may be possible, creating new tools for non-proliferation
  - CEνNS allows for miniaturization of neutrino detectors
  - Can possibly extend reach below IBD threshold [3]

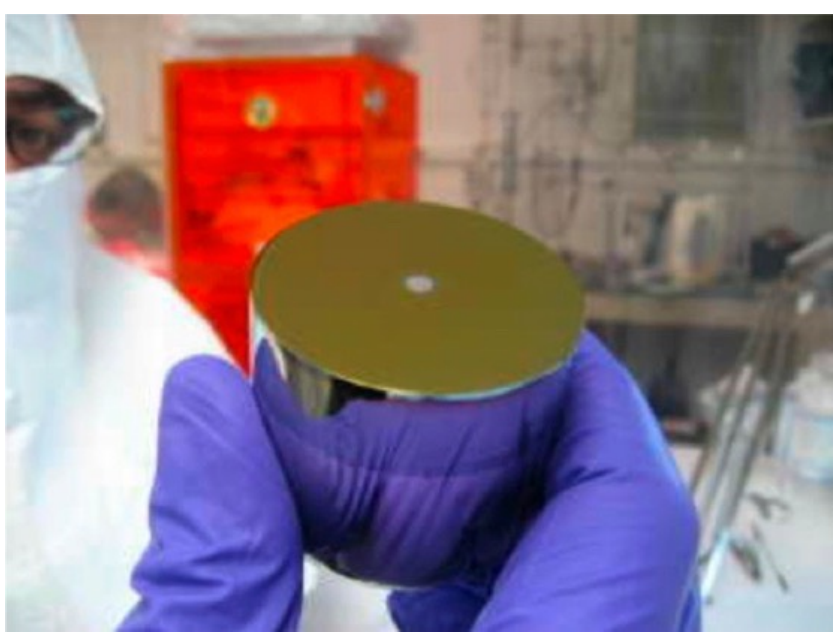
[1] K. Patton *et al.*, Phys. Rev. C 86 (2012)
[2] C. Horowitz & J. Piekarewicz, Phys. Rev. Lett. 86 (2000)
[3] B.K. Cogswell & P. Huber, Sci. Glob. Sec. 24 (2016)

Figure from [1]

CEνNS becomes a background

- Goodman & Witten recognize utility of CEνNS-sensitive detectors as potential dark matter detectors [1]
  - DM and CEνNS interactions are both coherent scattering processes with the same detectable signature (gently recoiling nuclei)
- Numerous instances of proposed CEνNS detectors turning instead into competitive DM searches



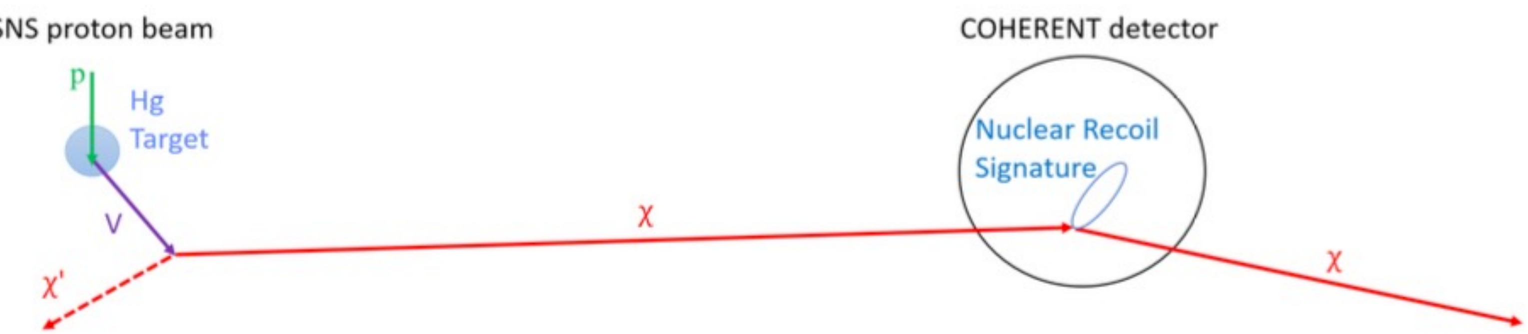

P.S. Barbeau, Ph.D. thesis (UChicago 2009)

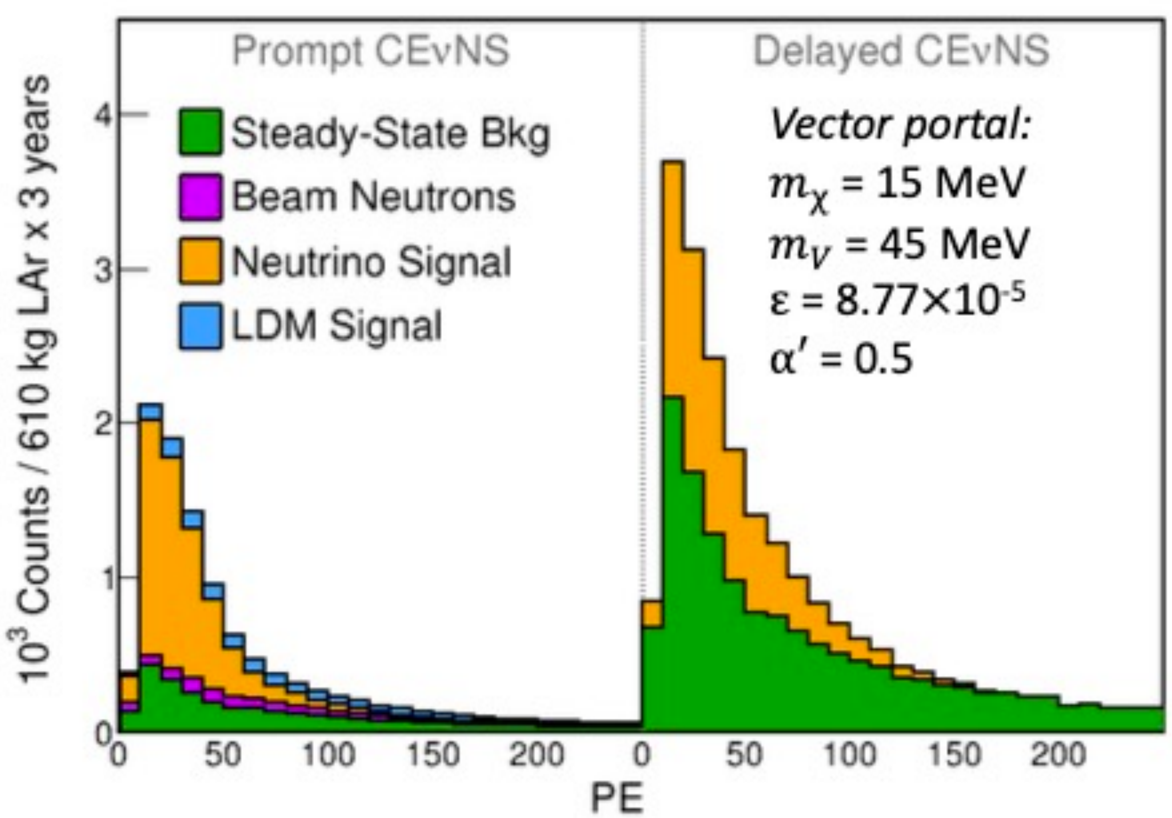
- Tremendous advances in detector technology to build more sensitive DM searches
- Next generation of WIMP detectors will begin to be sensitive to CEνNS from ^{8}B solar neutrino flux
  - This "neutrino floor" brings the CEνNS and DM relationship full circle

[1] M.W. Goodman, E. Witten, Phys Rev D 31 (1985)
Figure from http://cdms.berkeley.edu/limitplots/

CEνNS becomes a background

- CEνNS-sensitive detectors can be used in other (non-WIMP) dark matter searches, as well
- Accelerator-produced dark matter could manifest as signals in large detectors
  - Another instance where CEνNS is a background!





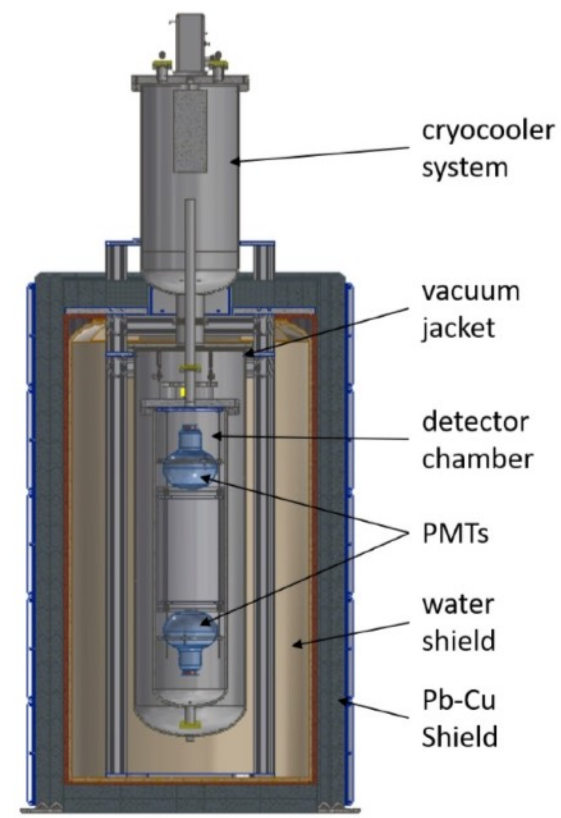
- Timing can play critical role in constraining CEvNS background these searches!
- For details, see recent sensitivity study for ton-scale LAr detector at COHERENT/SNS carried out by Dan Pershey (Duke postdoc) [1,2]

[1] D. Akimov *et al.* (COHERENT), 1911.06422
[2] D. Pershey, Magnificent CEvNS 2019

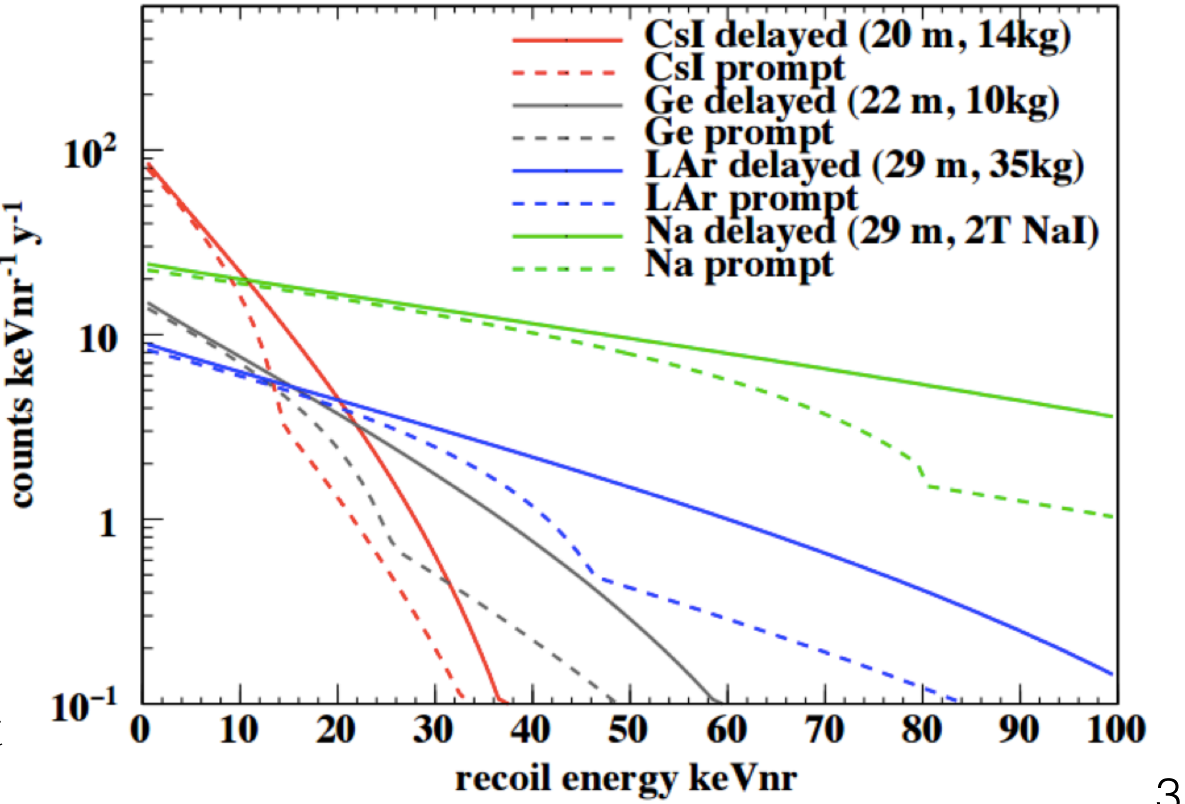
COHERENT physics moving forward

- Measure NINs cross section in ^{208}Pb, ^{56}Fe
- Measure ^{127}I CC cross section
    - 185-kg NaIνE collecting low-gain CC data now; continue in 2-T phase in parallel with high-gain mode
    - Sensitivity to g_A quenching with Q~$\mathcal{O}$(10 MeV)
- N^2 dependence of CEνNS cross section
    - Several distinct N values represented in COHERENT suite of experiments
    - 22-kg LAr detector already collecting CEνNS data, plans for 16 kg of Ge PPCs and 2-T NaI[Tl]
- Begin to perform precision CEνNS measurements
    - High-resolution, low-threshold detectors, such as Ge PPCs, enable access to exciting physics, e.g. electromagnetic properties of neutrinos
    - Improve understanding of timing characteristics at SNS

CENNS-10 LAr detector



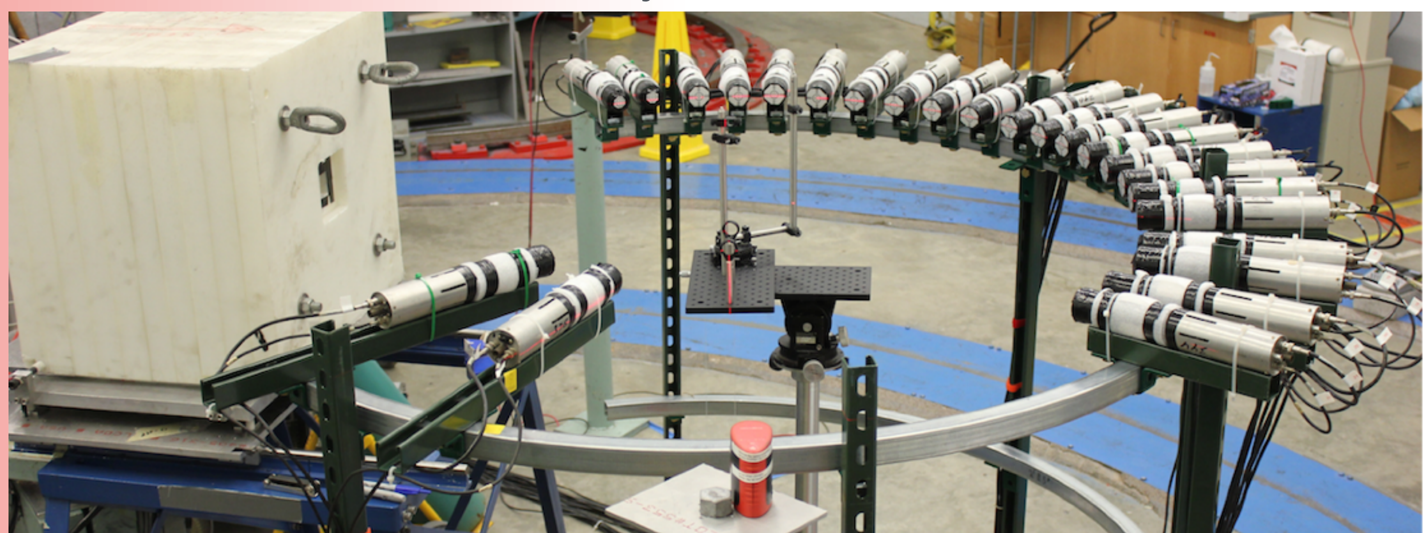
NaIνE: NaI[Tl] neutrino experiment

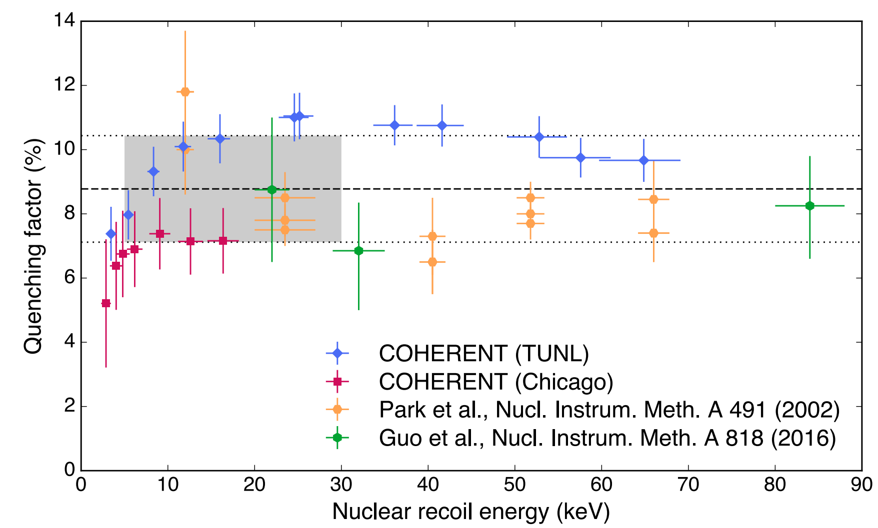


Reducing dominant systematic uncertainties

Quenching factors

- Understanding of QF is crucial for *all* CEνNS measurements
  - Reanalyzing original data and collecting new data to resolve discrepancy in COHERENT QF measurements for CsI[Na]
  - Some data already collected and future measurements planned for Ge and NaI[Tl]





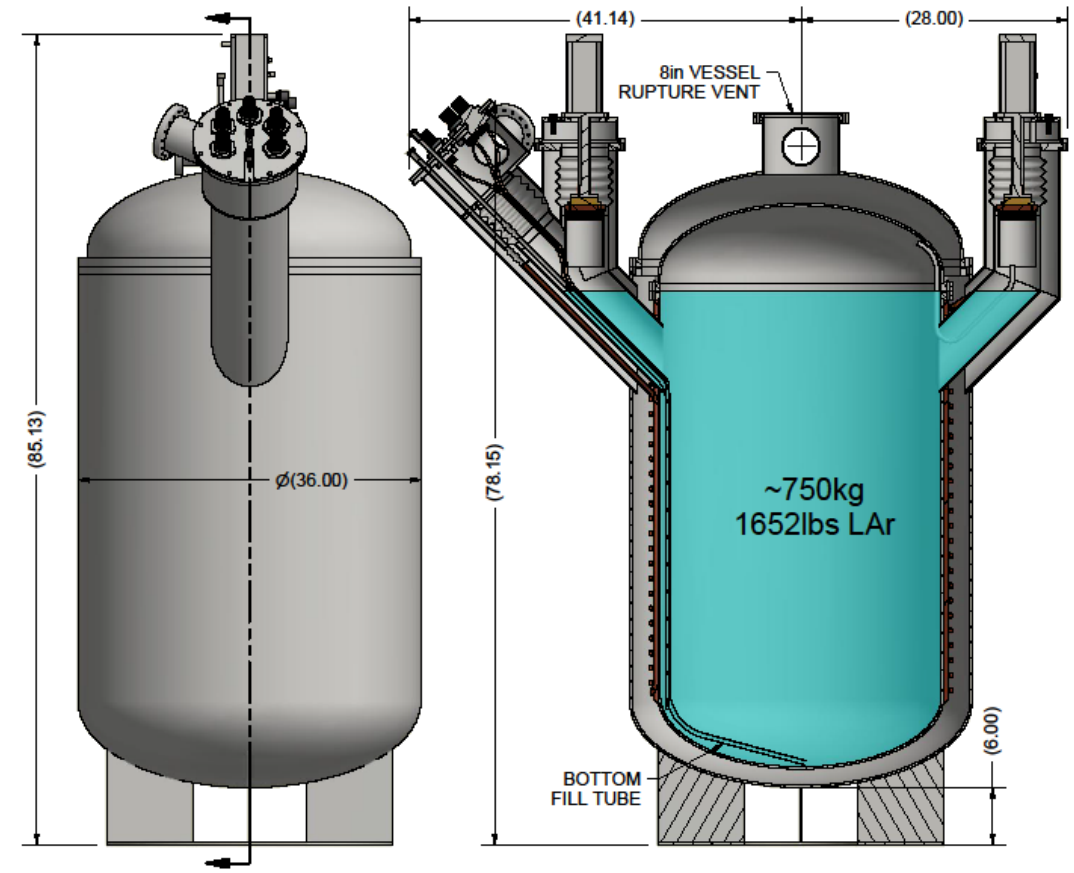
ν flux normalization

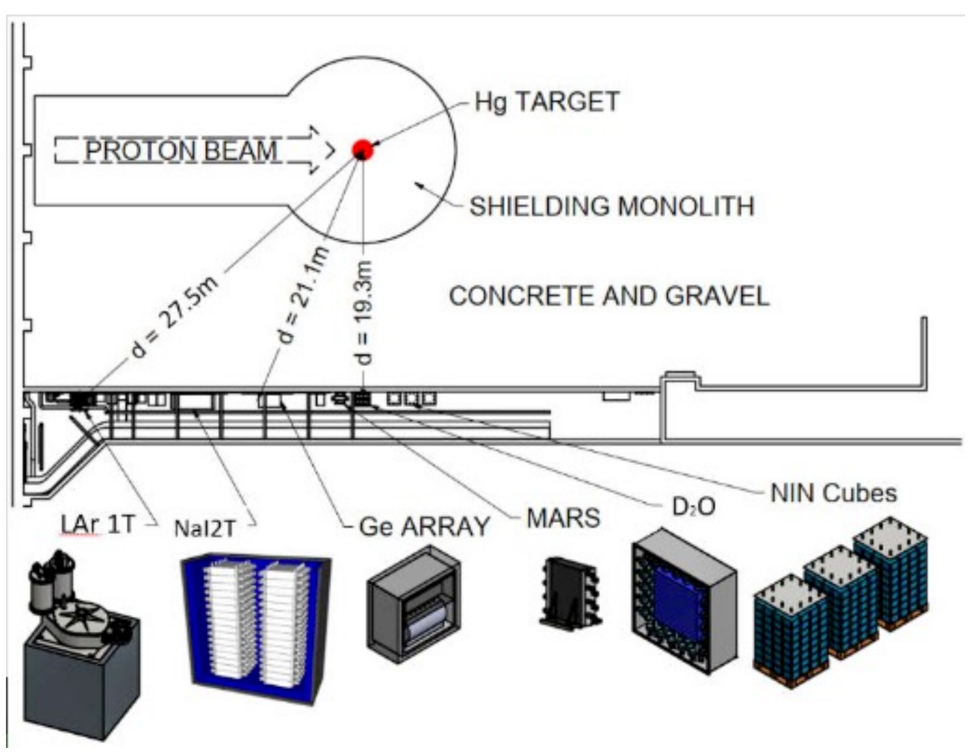
- Indirect approaches to flux determination possible (e.g., improved input for models or direct measurement of pion production at SNS)
- Conceptual design stages of a D_2O detector for neutrino alley relying on CC interaction on D
  - D cross section is relatively well understood theoretically [1] and previous measurements agree with predictions [2]

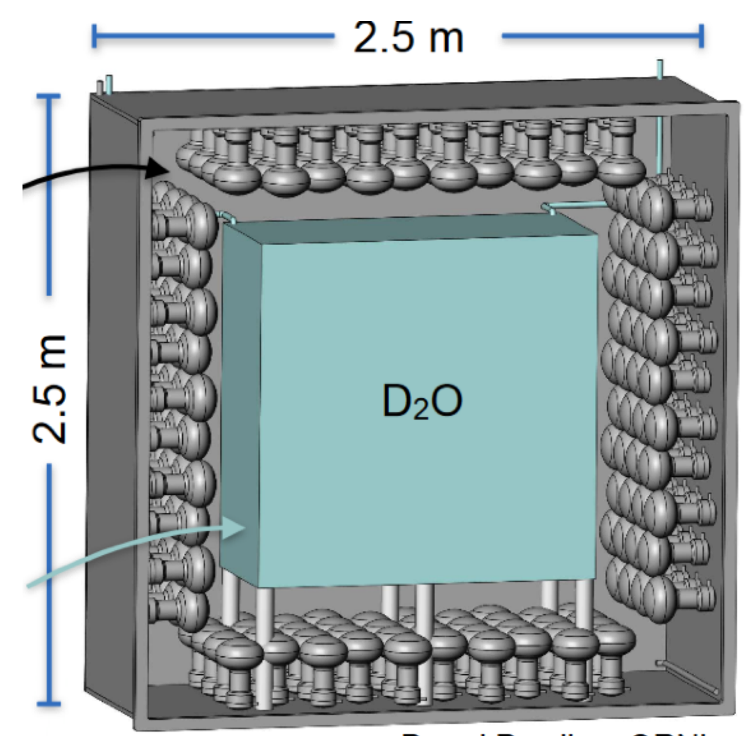
[1] S. Nakamura *et al.*, Nucl. Phys. A 721 (2003)
[2] J. Formaggio and G.P. Zeller, Rev. Mod. Phys. 84 (2012)

Mid-term future of COHERENT

- Next stages of COHERENT CEνNS measurements will be a considerable scale up
  - Beginning plans for $\mathcal{O}$(1 ton) LAr detector using underground argon
  - Development advancing for multi-ton NaI[Tl] detector capable of simultaneous CC and CEνNS measurement; designing new PMT-base electronics to facilitate this parallel measurement
- Flux normalization measurements benefit all COHERENT experiments; early design stages
- Ge deployment (2020)







Darryl Dowling, ORNL

Community efforts

- Three important goals
  - Building collaboration / communication
  - Shared resources / expertise
  - Data openness / sharing

Global CEνNS efforts

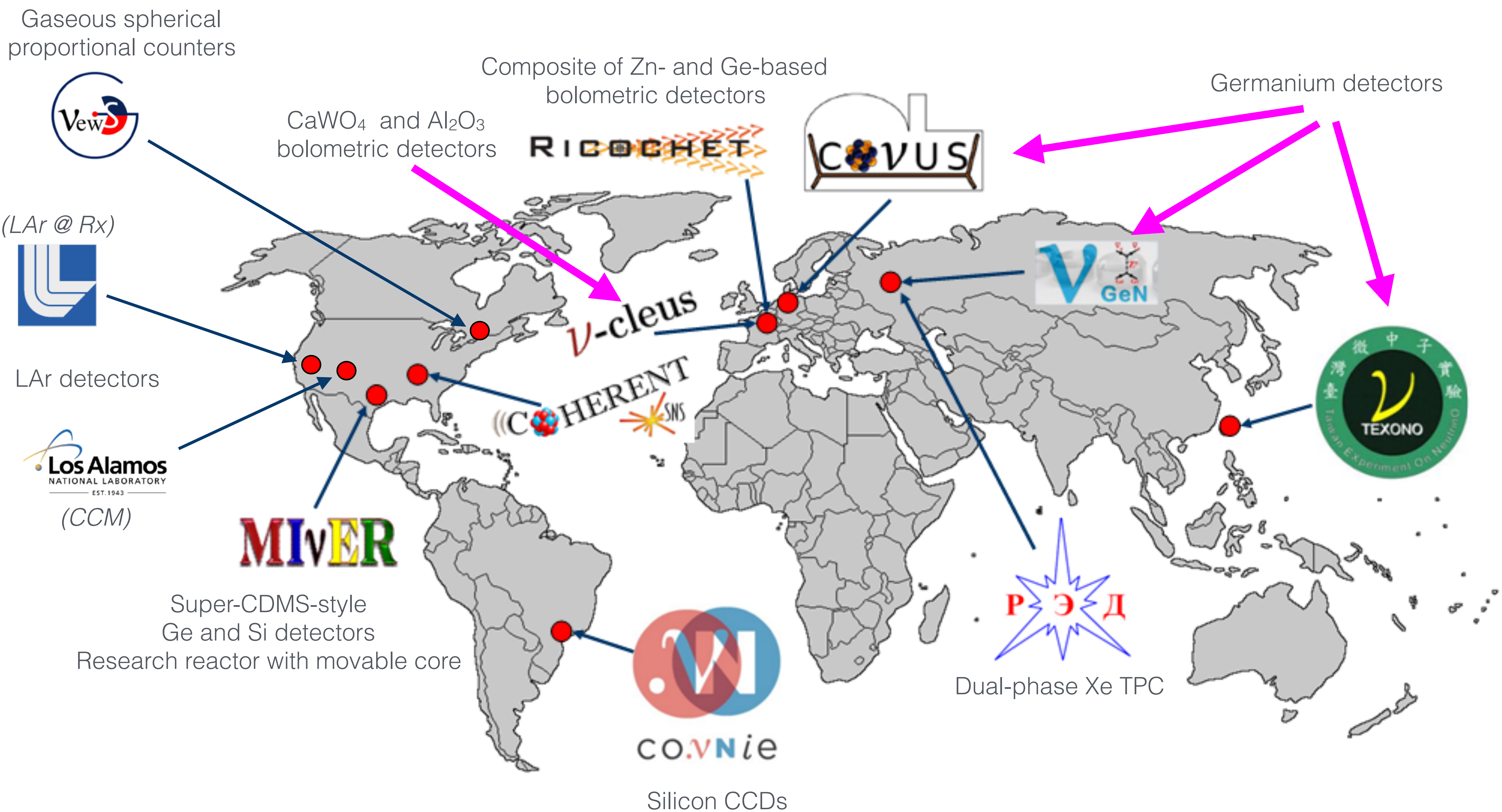
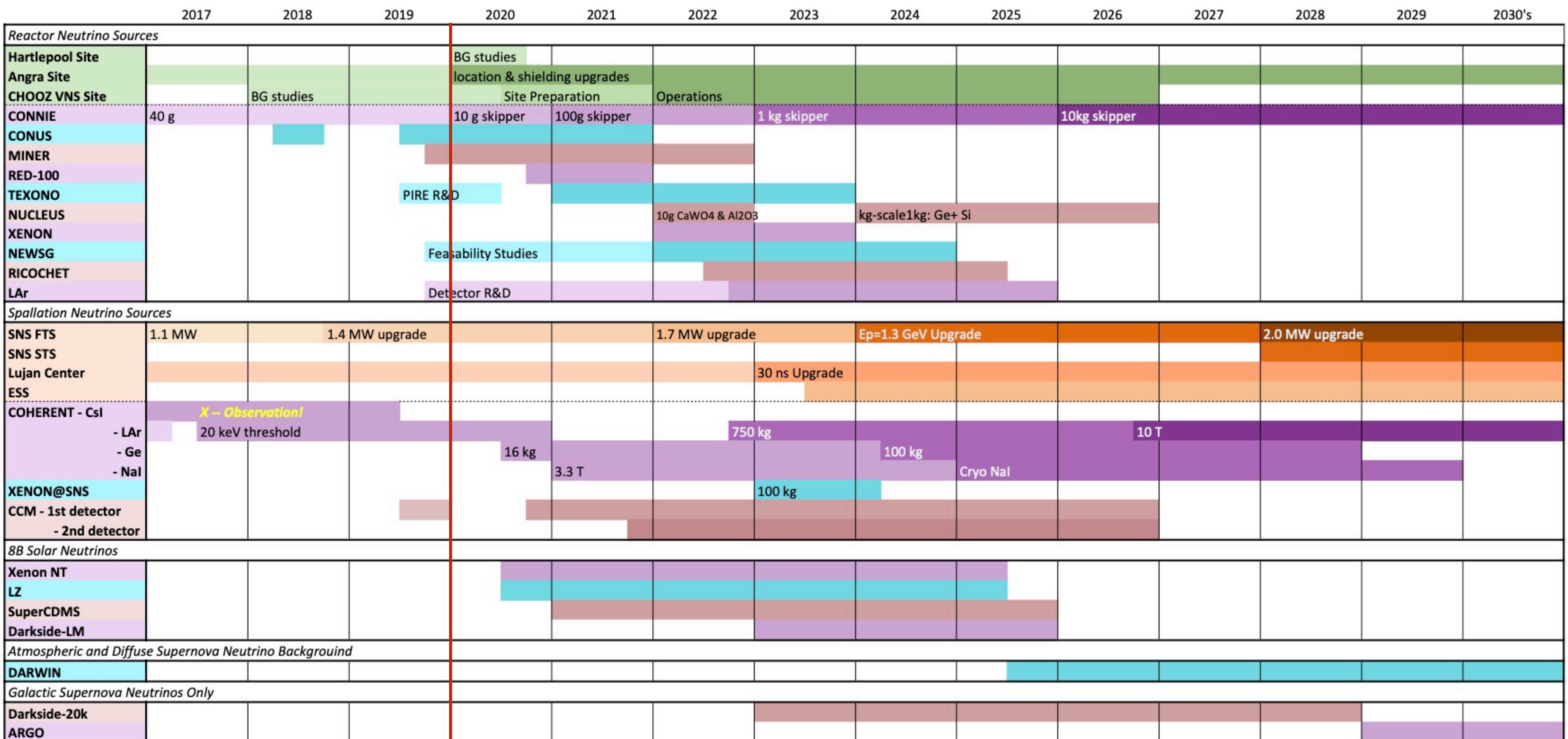


Figure from Alexey Konovalov

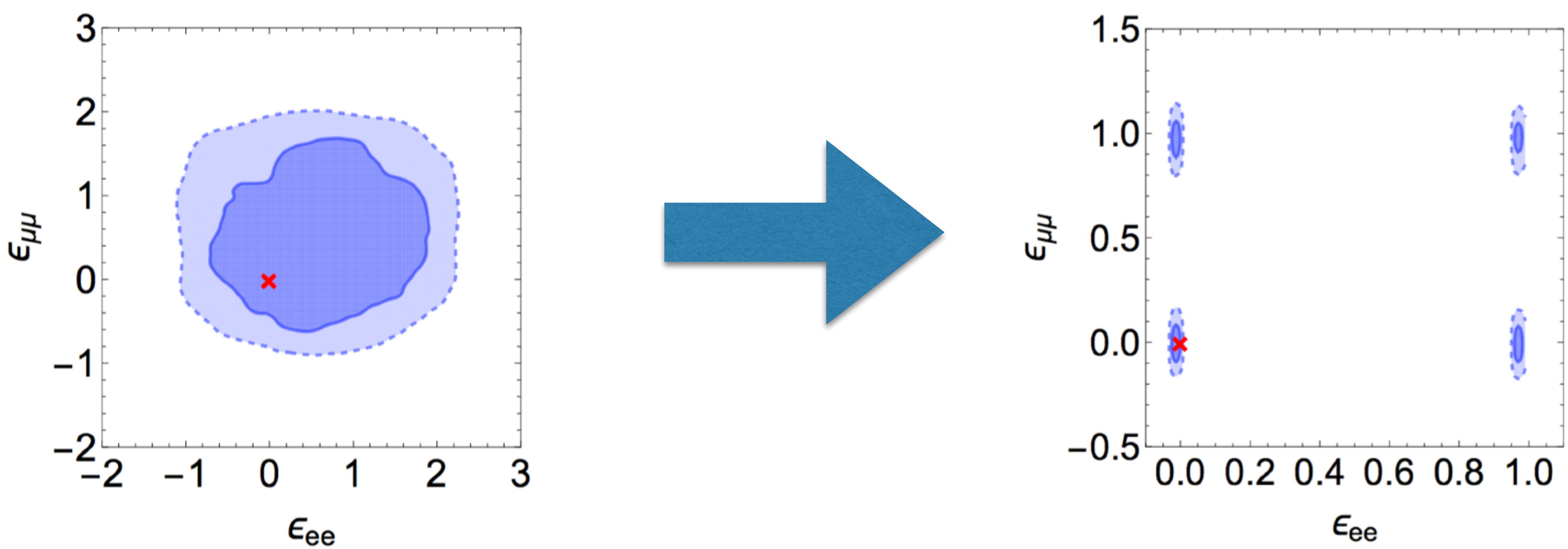
Global CEνNS efforts



The next few years will be an exciting time in the CEνNS community!
Very good time to be involved, and considerable opportunities for involvement

Complementarity of CEνNS efforts

- The distinct efforts seeking to measure CEνNS are *highly complementary*
- At the simplest level, different detectors or sources allow for independent systematics
- Different nuclear targets and different sources (energies/flavor composition) allow for isolation of certain physics sensitivities
  - NSI parameter constraints are *significantly* improved when accelerator and reactor experiments are combined in a joint analysis of projected measurements [1]
  - Reactor experiments are not very sensitive to nuclear form factor (mitigates systematic) where stopped-pion experiments do have this sensitivity (allows for measurement of neutron distribution)



[1] J.B. Dent *et al.*, Phys. Rev. D 97 (2018)
Figures from [1]

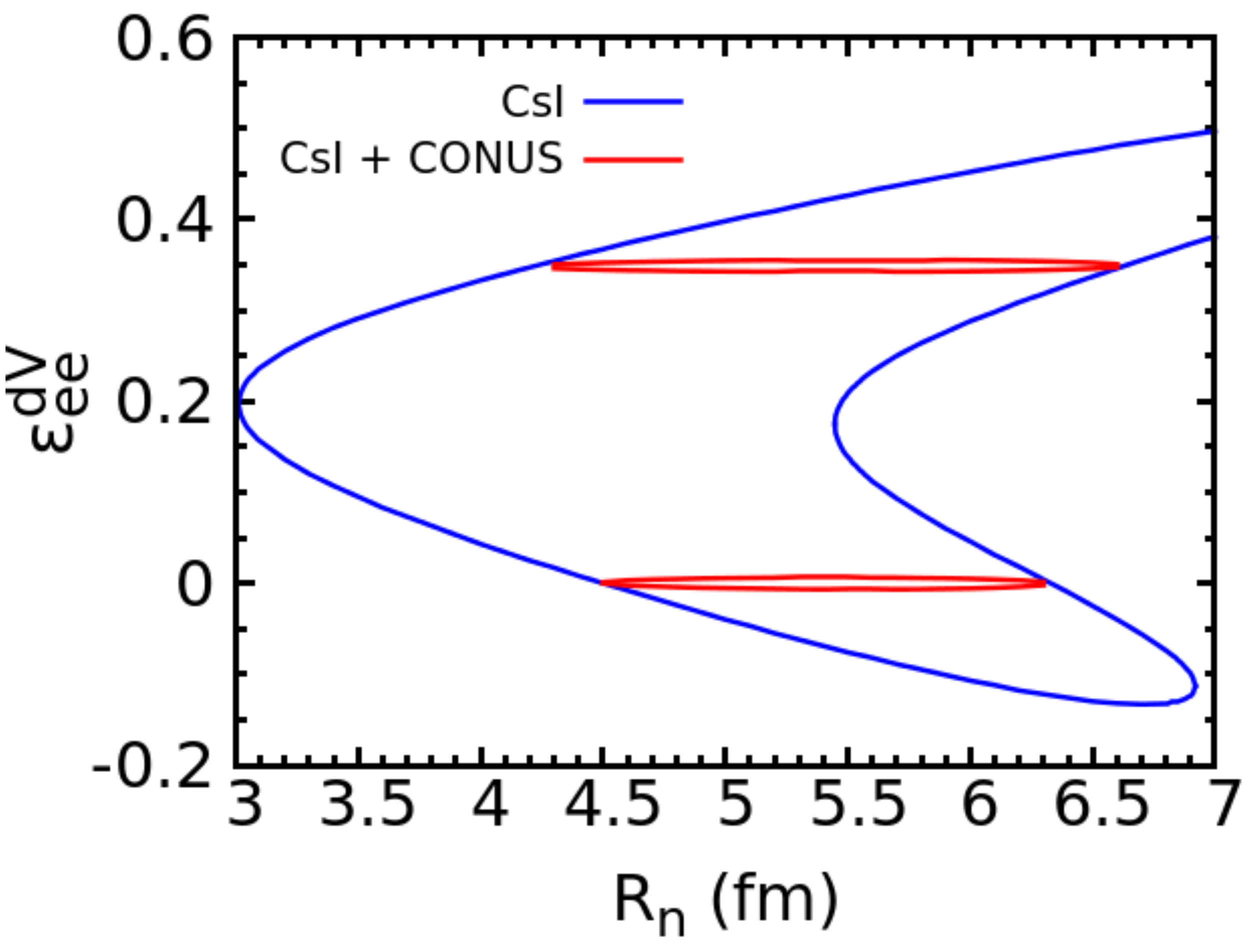
Community workshop series

- Magnificent CEvNS workshop
  - Nov 2-3, 2018, Chicago (~70 attendees; magnificentcevns.org/2018)
  - Nov 9-11, 2019, Chapel Hill, NC (~90 attendees; magnificentcevns.org/2019)
  - *Sept 16-18 (tentative), 2020, Munich*
- Goal is to promote collaborative spirit within broad CEvNS community and foster community-wide efforts
  - With some alignment around the common touchstone of CEvNS, there could be scientific impact across numerous fields
  - Community white paper effort established in anticipation of Snowmass process (info / links on 2019 M7s Indico site)

M7s 2019 banquet photo (credit: Jeannie Cox)

Interplay between nuclear and particle physics

- Recent efforts, reflecting (if not directly influenced by) discussions at M7s meeting, explore the interplay between nuclear physics and BSM sensitivities [1]
- This is precisely the kind of inter-disciplinary discourse M7s is meant to encourage!



[1] B.C. Canas *et al.*, 1911.09831
Figures from [1]

Low-energy nuclear recoils from CEνNS

- Signature of CEνNS in a detector is a low-energy nuclear recoil
- To properly interpret collected data, it is of paramount importance that detector response at these *nuclear recoil* energies be well understood
- Uncertainty in detector threshold translates into uncertainty in measured cross section
  - Situation worse for heavier targets

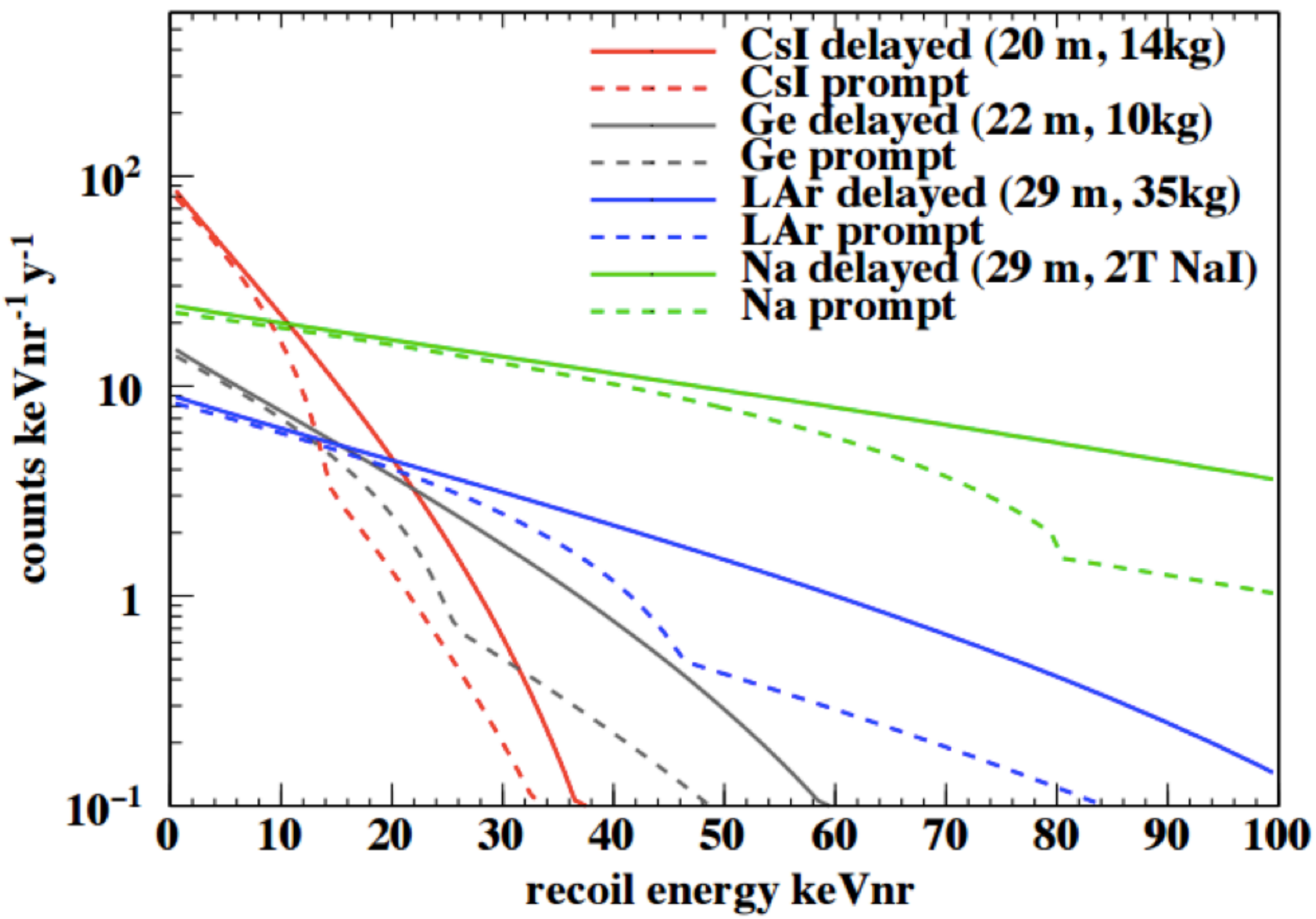
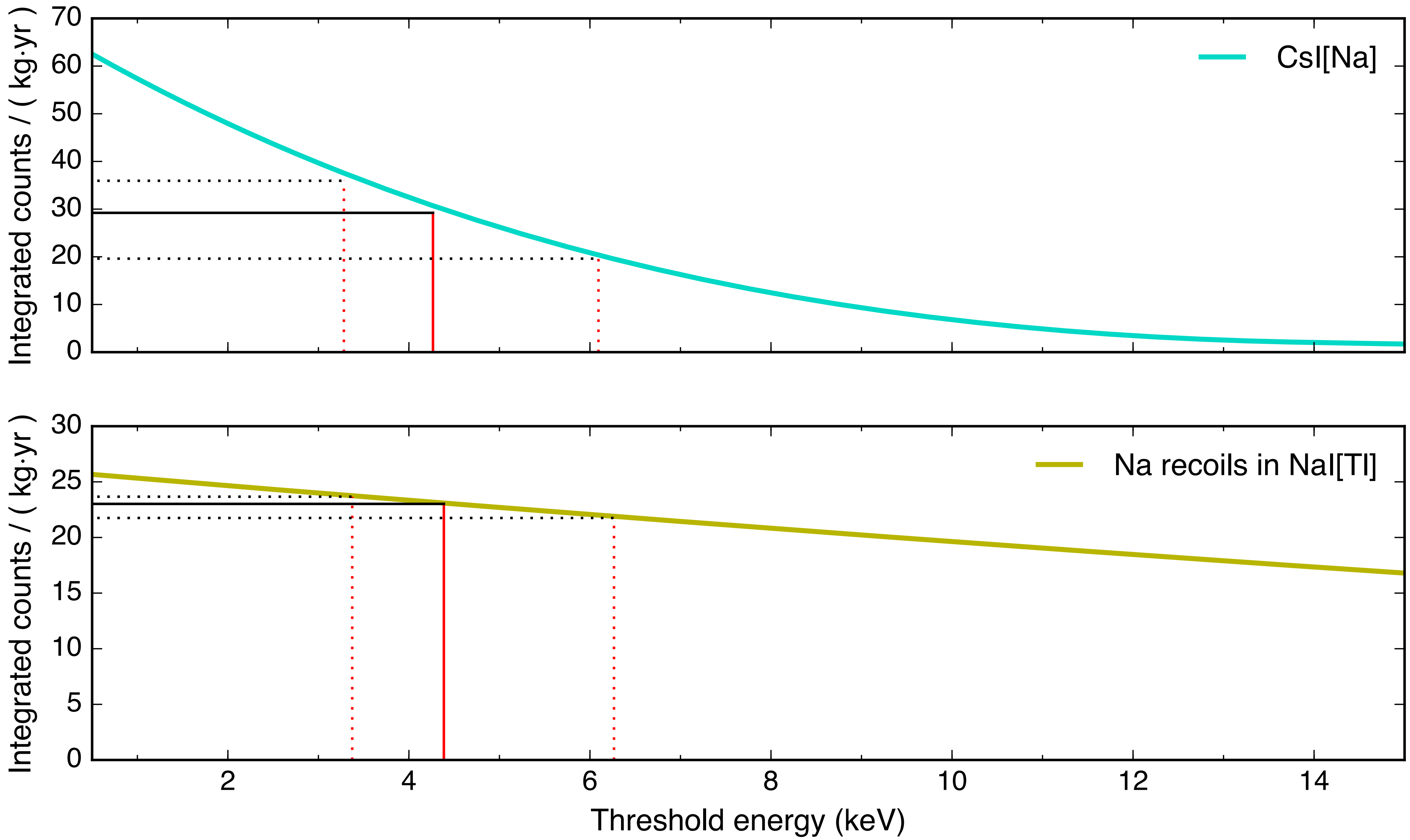


Figure from the COHERENT Collaboration

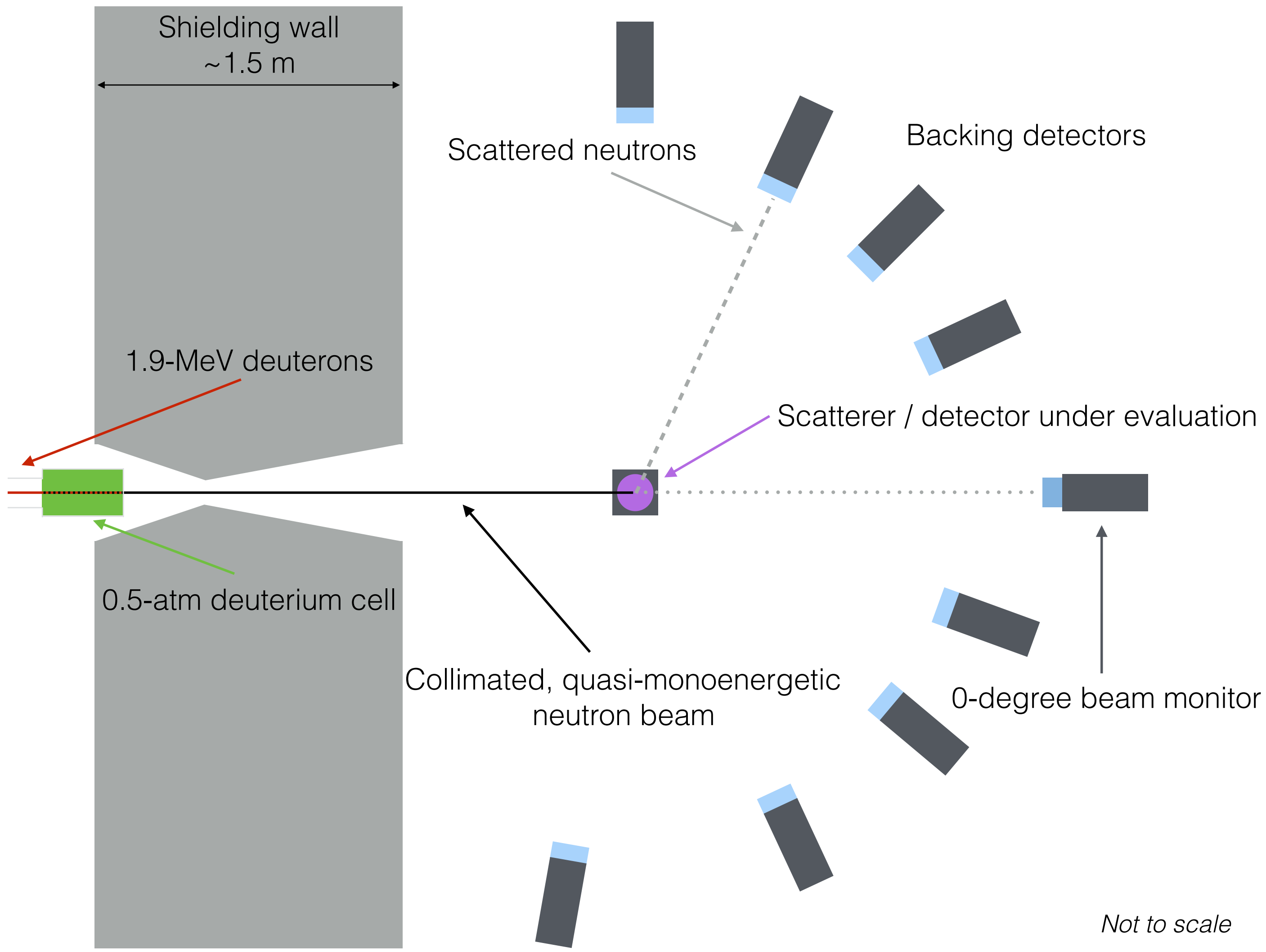
Low-energy nuclear recoils from CEνNS



- Simple model: assume 30% uncertainty on QF for both CsI[Na] and NaI[Tl}
  - NaI[Tl] counts above threshold has resulting ~5% uncertainty
  - CsI[Na] counts ~30% uncertainty

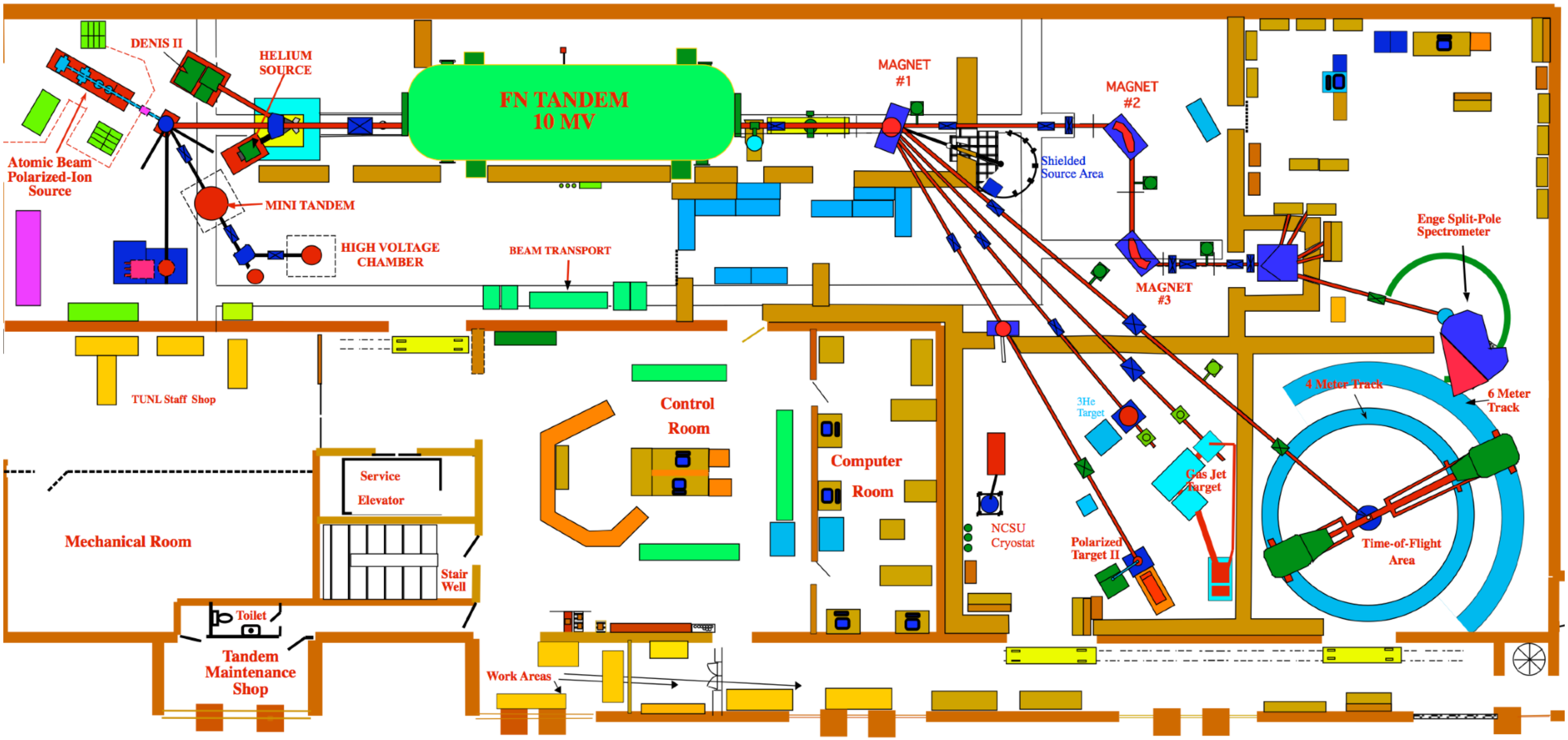
Low-energy nuclear recoils from neutron scattering

- Quasi-monoenergetic neutron beam scattered by central detector into fixed angles covered by "backing" detectors; nuclear recoil energy kinematically well defined



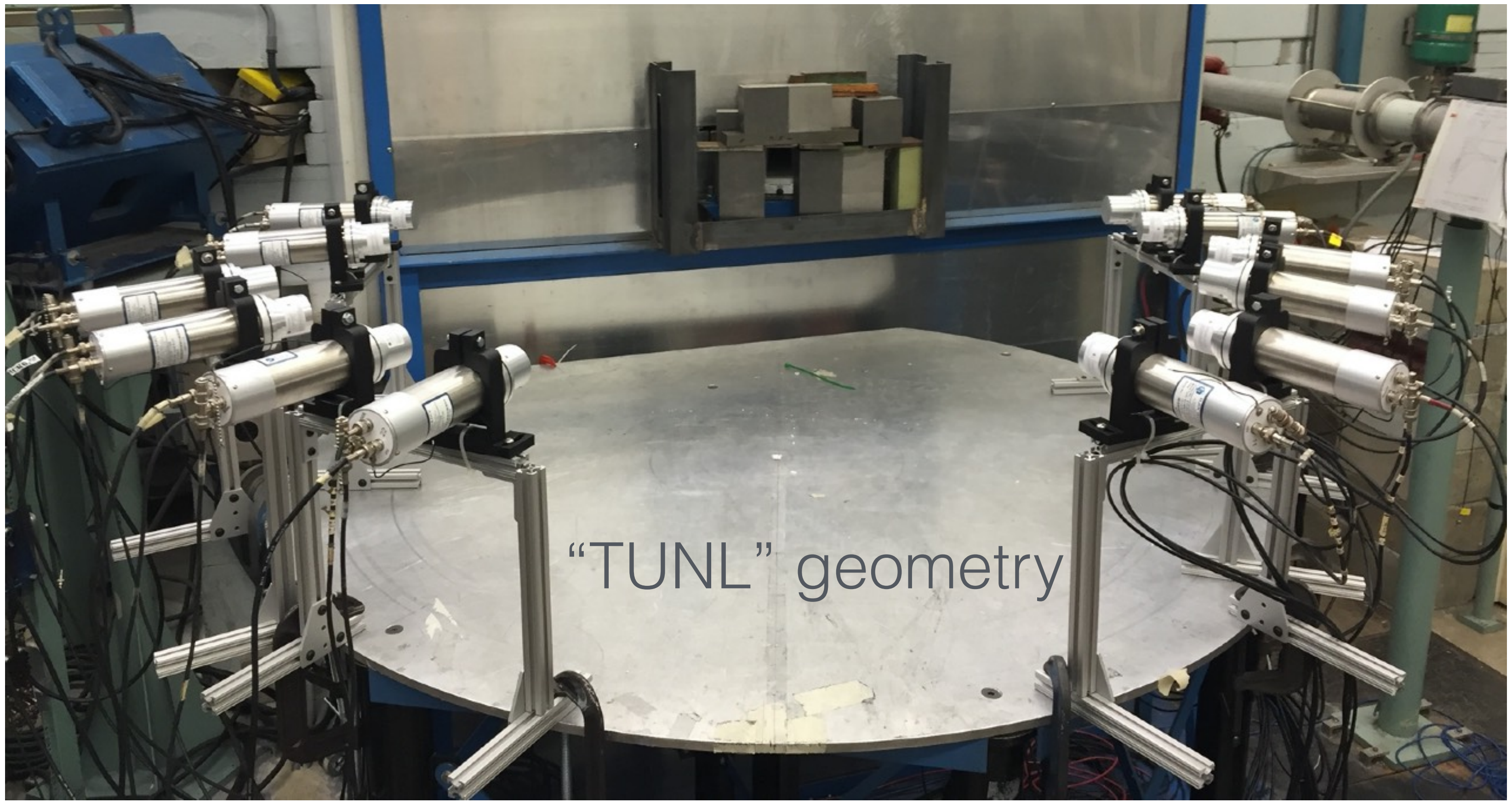
$$\Delta E = 2E_{\mathrm{n}} \frac{M_{\mathrm{n}}^2}{(M_{\mathrm{n}} + M_{\mathrm{T}})^2} \left(\frac{M_{\mathrm{T}}}{M_{\mathrm{n}}} + \sin^2\theta - (\cos\theta)\sqrt{\left(\frac{M_{\mathrm{T}}}{M_{\mathrm{n}}}\right)^2 - \sin^2\theta} \right)$$

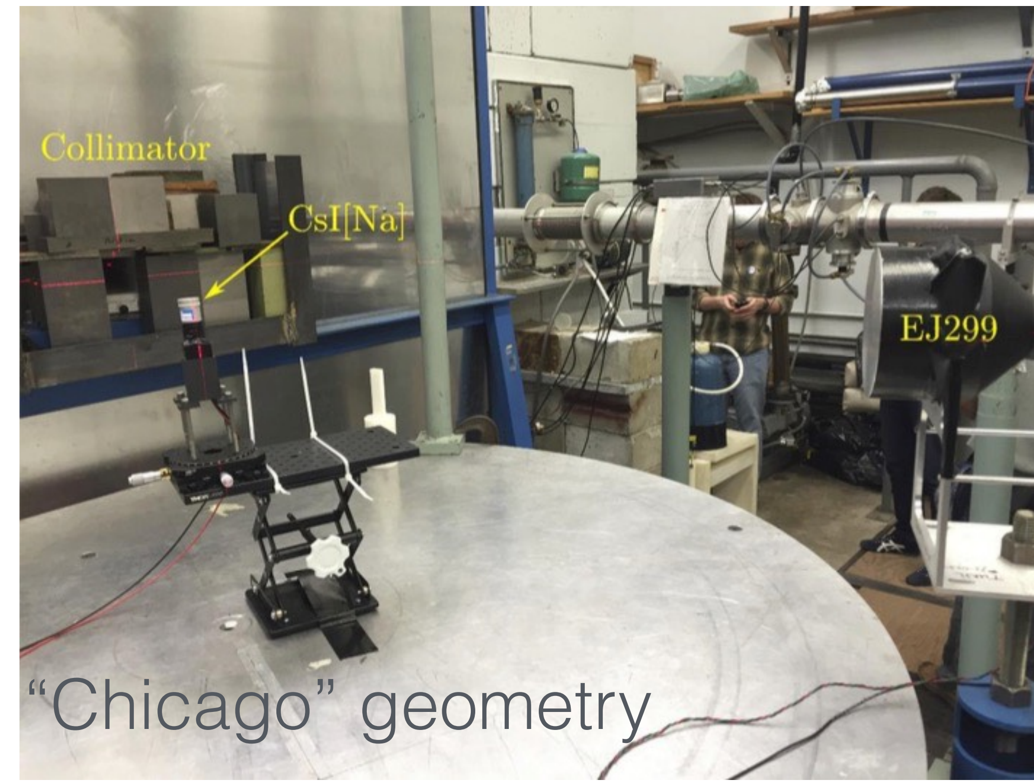
Tandem accelerator lab at TUNL



- 3 ion sources
- Beam can be bunched and chopped
- 10-MV maximum terminal voltage
- Numerous beam lines and experimental areas

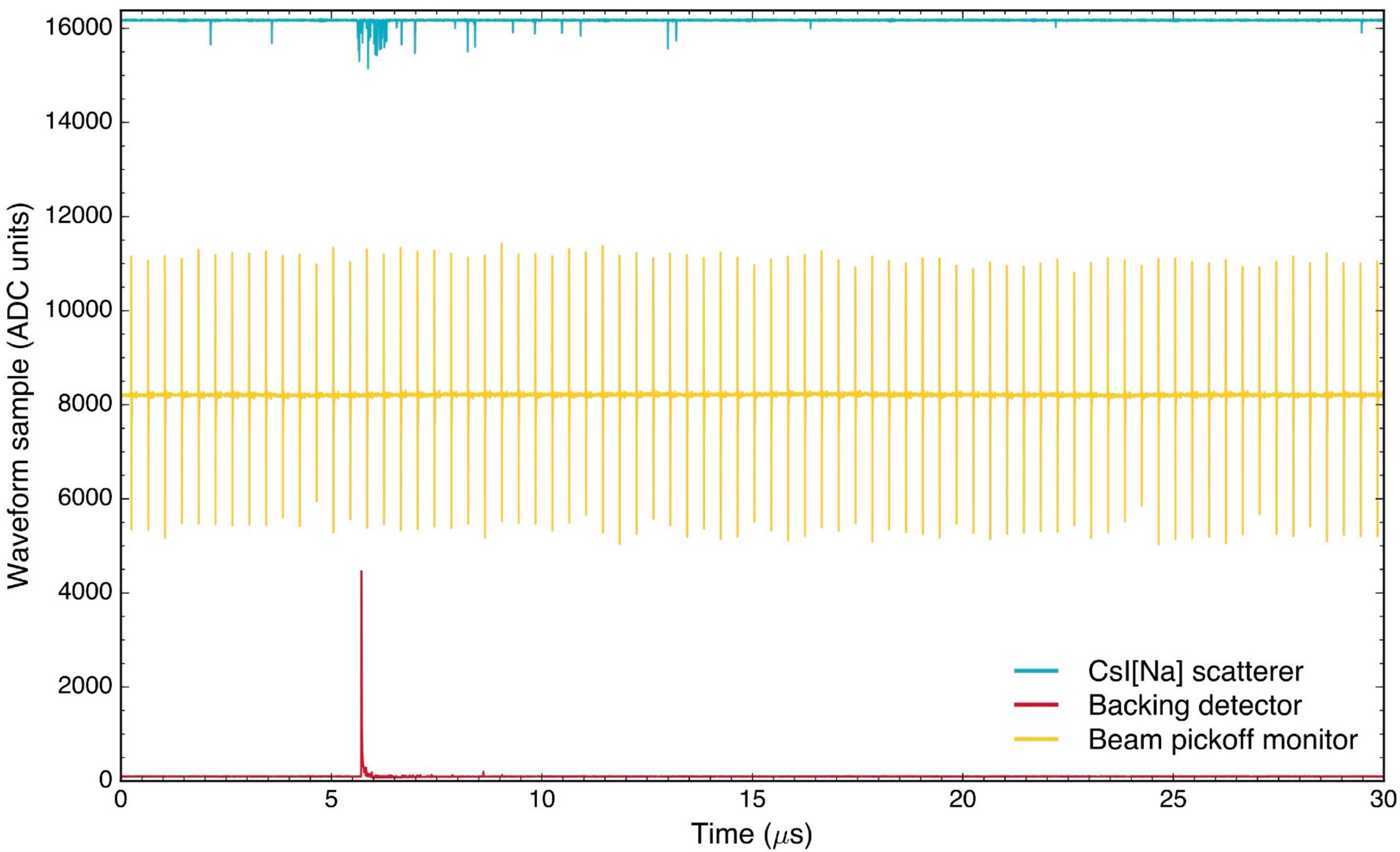
Quenching factor measurements at TUNL



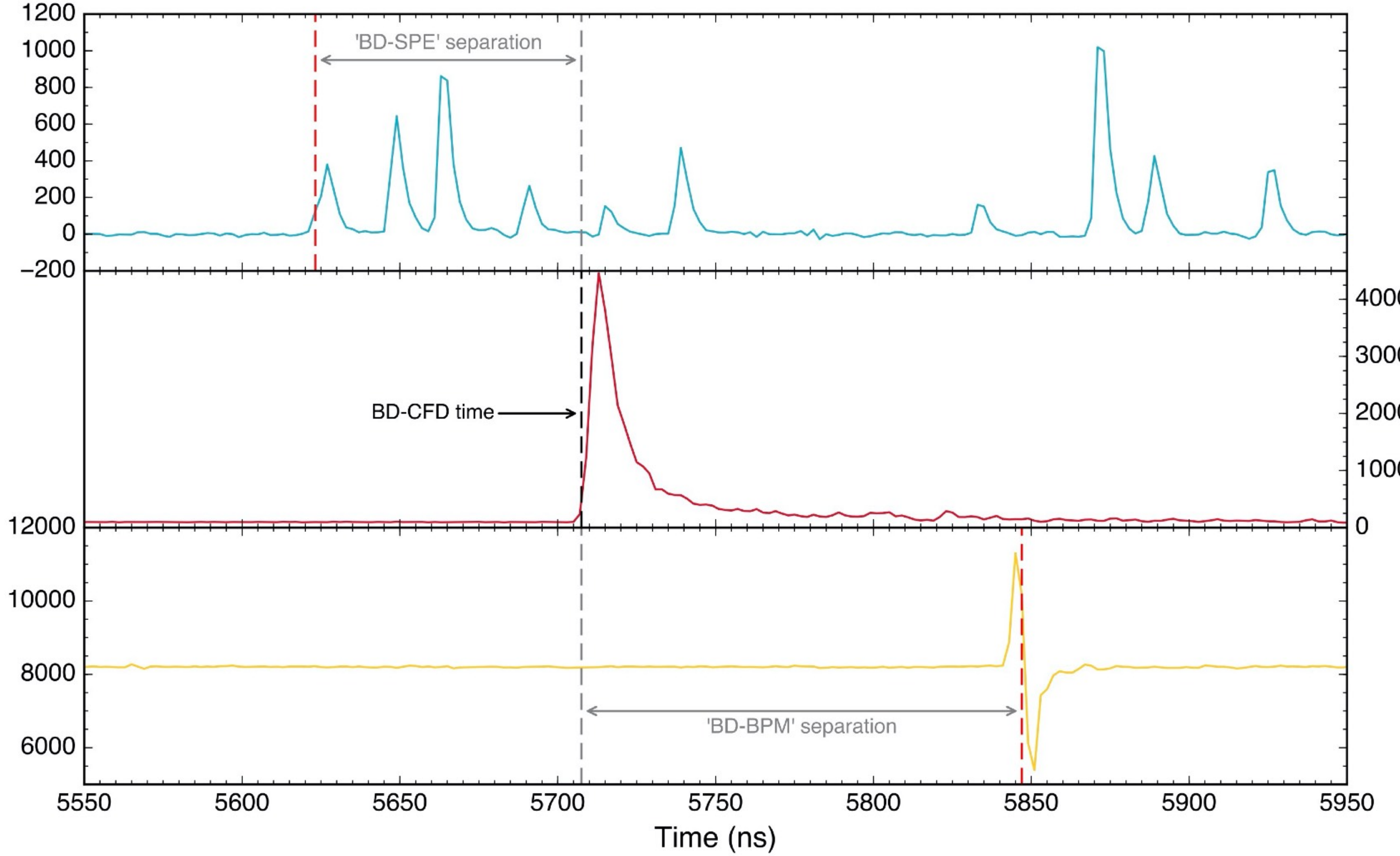


- Neutron beam produced by pulsed deuteron beam incident on deuterium gas cell
- Scattered neutrons detected by "backing detectors"
- Angle of backing detector selects well-defined nuclear recoil energy

Anatomy of an event



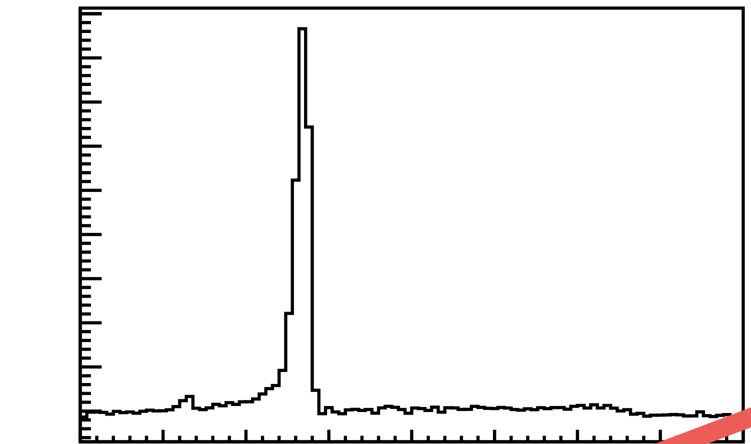
Anatomy of an event

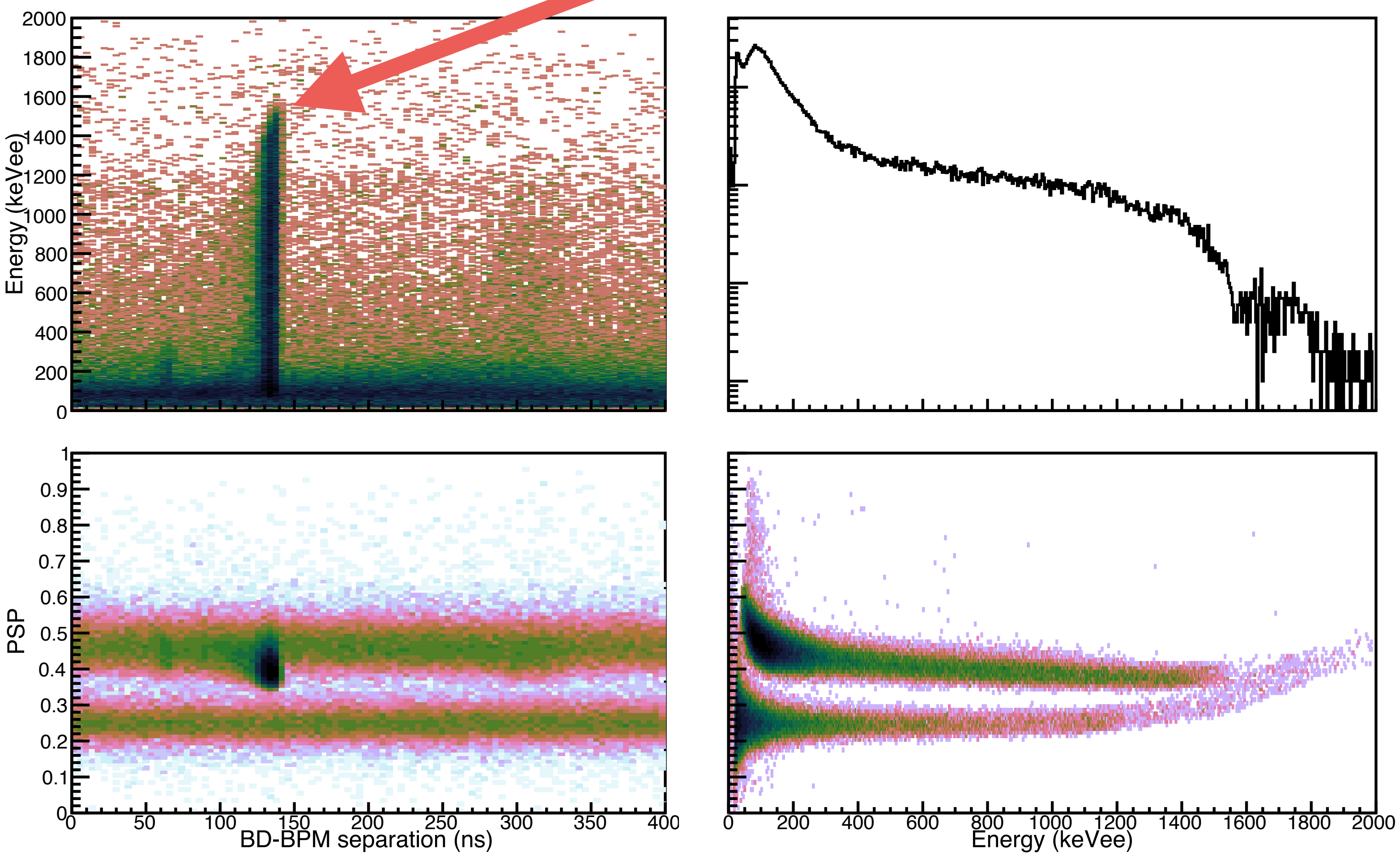


Isolation of beam-related neutron events

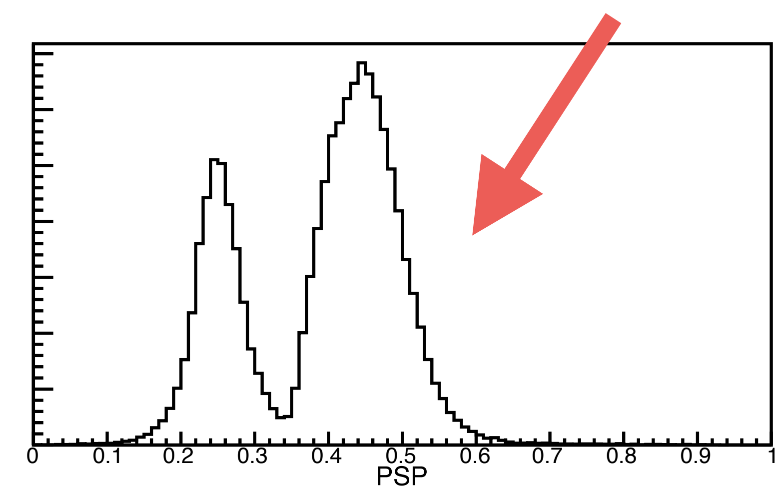
- By analyzing signals from the backing detectors alone, along with timing information, we can significantly reduce background
- Efficacy of cuts and availability of information will depend on experimental configuration

Energetic neutrons may stand out from steady-state background neutrons in energy space





Low-energy neutrons may not yield useful pulse-shape information in BDs



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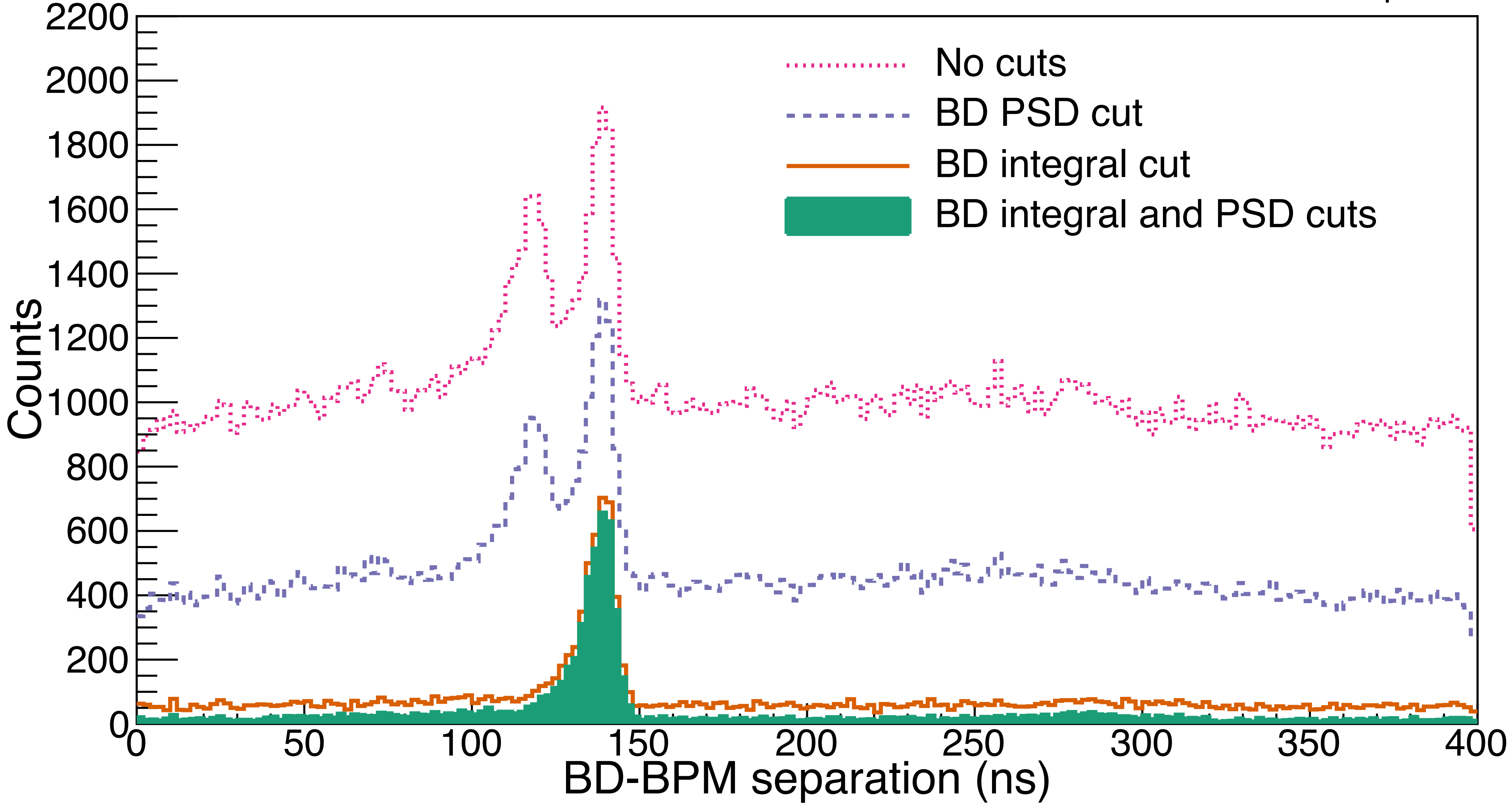
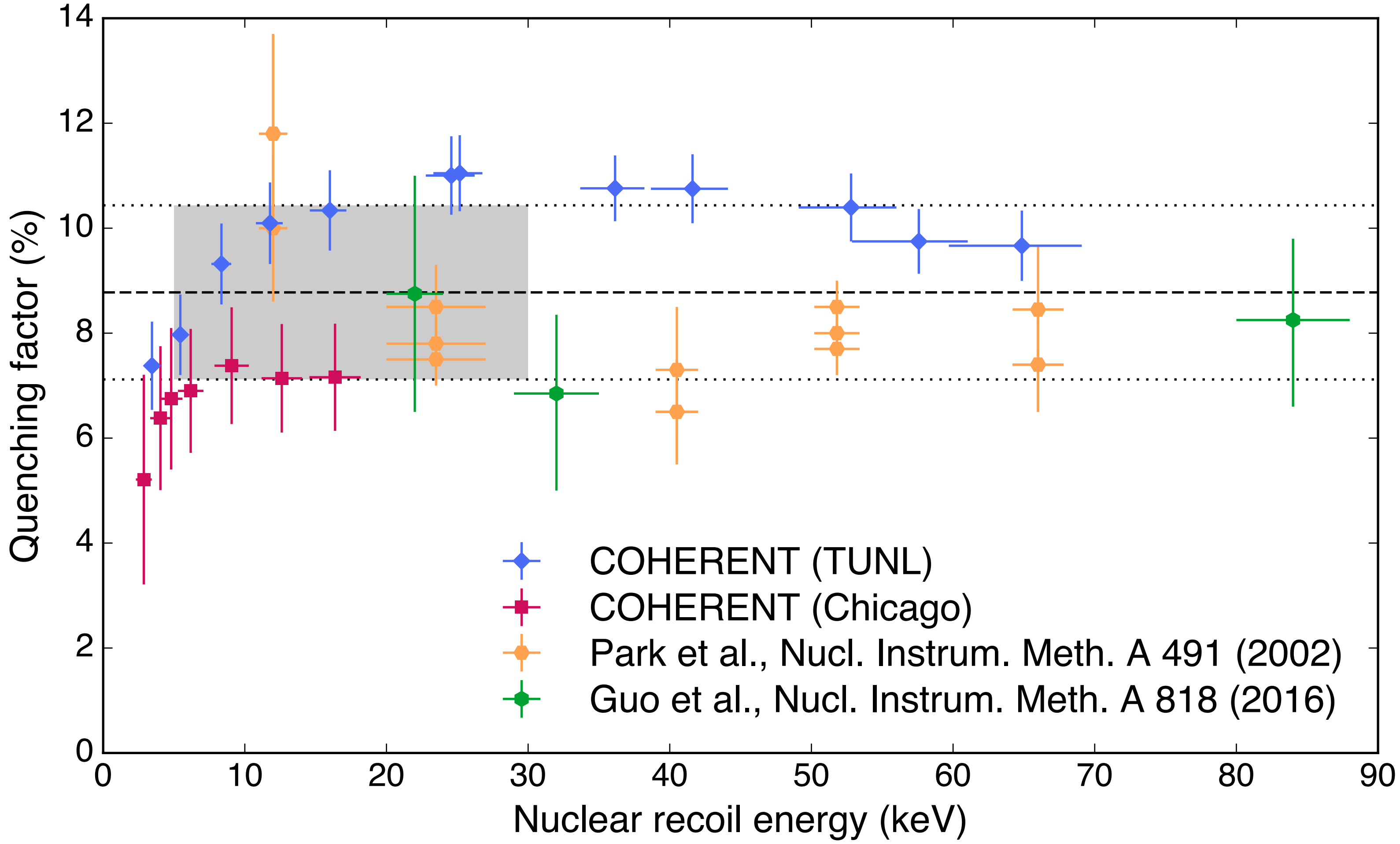


COHERENT SNS

Results of COHERENT CsI[Na] QF measurements



- Determine QF from global values in range from 5 to 30 keVnr
  - 8.78 +/- 1.66%

- Both COHERENT measurements show downward trend at lower recoil energies

- Disagreement between COHERENT measurements under (re)analysis

COHERENT CEνNS observation data release

- Data that constituted CEνNS observation has been packaged and is publicly available
  - http://dx.doi.org/10.5281/zenodo.1228631
  - https://coherent.ornl.gov/data
- Should include all information necessary to perform further analyses on CsI[Na] data
  - Binned data for coincidence and anticoincidence regions for both SNS on and off; prompt-neutron model
  - Descriptions and values for relevant systematics
- Collaboration intends to continue practice of data releases
- Want to promote *even more sharing*, not simply from COHERENT
  - Value in *transparency* and *portability / reusability*

Only the beginning…

- CEνNS predicted in 1974 but unobserved until 2017
  - Observed at 6.7-σ level using 14.6-kg CsI[Na] scintillator deployed at pulsed, stopped-pion ν source (SNS)
- COHERENT continues to search for CEνNS with numerous detectors (LAr, NaI[Tl], Ge PPCs) in addition to several other efforts
  - Working towards performing *precision* CEνNS measurements
- Many other groups seeking observation with many different kinds of detectors, different neutrino sources
  - Examples: CONNIE, CONUS, MINER, Nu-CLEUS, nuGEN, RICOCHET, RED-100
  - These efforts are *complementary!* Joint analyses using different detectors and/or sources are very powerful
- Tremendous amount of physics left to be done with CEνNS
  - Robust and collaborative community forming around the process, ample opportunity for involvement!

COHERENT SNS

U.S. DEPARTMENT OF ENERGY

NSF

NNSA National Nuclear Security Administration

KICP Kavli Institute for Cosmological Physics AT THE UNIVERSITY OF CHICAGO

CNEC Consortium for Nonproliferation Enabling Capabilities

OAK RIDGE National Laboratory

Sandia National Laboratories

Duke UNIVERSITY

THE UNIVERSITY of TENNESSEE KNOXVILLE

W UNIVERSITY of WASHINGTON

VIRGINIA TECH

Tufts UNIVERSITY

NORTH CAROLINA CENTRAL UNIVERSITY FOUNDED 1910

THE UNIVERSITY OF CHICAGO

UF UNIVERSITY of FLORIDA

NC STATE UNIVERSITY

MEPhI NATIONAL RESEARCH NUCLEAR UNIVERSITY • MOSCOW ENGINEERING PHYSICS INSTITUTE

TUNL

Carnegie Mellon University

Laurentian University Université Laurentienne

KAIST

Los Alamos NATIONAL LABORATORY EST. 1943

BERKELEY LAB

NM STATE UNIVERSITY